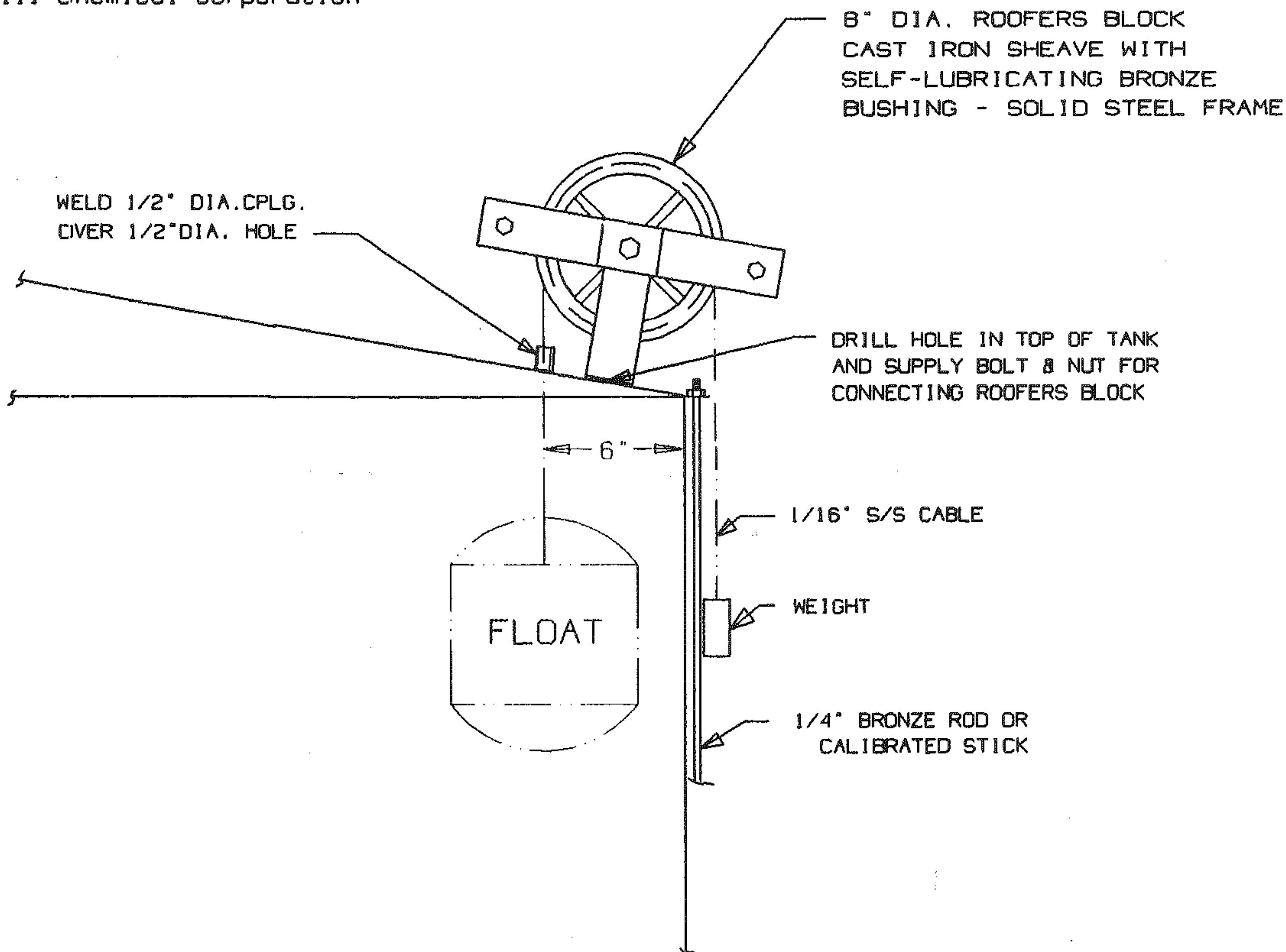
EXHIBITS

Hukill Chemical Corporation




DETAIL 'D'

LEVEL GAGE ARRANGEMENT

V-114, V-214, V-314,
V-414, V-117 Tanks

Exhibit D-1

Section D

Exhibit D-2

# EXHIBIT D - 2

# NEW TANK SYSTEM ASSESSMENT

**FOR**

# 7-TANK DIKE SYSTEM

**CONTAINING TANKS**

## V-114, V-214, V-314, V-414, V-514, V-614 and V-120

**Prepared March, 1996**

**By**

**Edgar M. Price, Engineering Consultant**

# TABLE OF CONTENTS FOR EXHIBIT D-2

## INTRODUCTION

Hukill Chemical Corporation (HCC) operates a chemical distribution and solvent recovery facility in Bedford, Ohio. HCC recycles industrial solvents using two thin film evaporators and a fractional distillation tower. HCC operates under RCRA interim status as a hazardous waste storage facility and has applied for a RCRA Part B Permit.

HCC completed construction of secondary containment for nine hazardous waste storage tanks pursuant to OAC 3745-66-92 and installed tanks identified as V-114, V-214, V-314, V-414, V-514, V-614, V-120, V-4000C and V-1500C in the containment area. Tank V-120 was a new tank to HCC's facility and replaced the V-714 tank which was scraped after the closure was approved by OEPA. Tanks V-4000C and V-1500C are only used to store hazardous waste for less than 90 days.

The original tank assessments for V-114 through V-116 were done for the HCC Part B Application in October, 1984, to January, 1986. V-114 through V-116 were in service as permitted hazardous waste storage tanks and then relocated to the new 7 Tank Dike in the Spring of 1989. After the tanks were relocated in 1989, OEPA advised that they were then determined to be new tank systems. The new tank assessment was done by Eder Associates Consulting Engineers (EA) in June, 1989. The assessment was revised in September, 1989, by EA to include the two less-than-90-day tanks, V-4000C and V-1500C.

This assessment is prepared at the request of OEPA to present more detailed and current information on the 7-Tank Dike tank systems.

## TANK SYSTEM DESCRIPTION

### 1. Storage Tanks

This 7-tank dike system consists of seven permitted tanks, V-114, V-214, V-314, V-414, V-514, V-614, V-120 and the two less-than-90-day storage tanks, V-4000C and V-1500C. With the exception of V-120, these tanks were relocated to the secondary containment storage tank area shown in **Figure 1**, "NEW 7-TANK DIKE - Constructed 1989", found on the next page. The tank V-120 was installed in 1989 as a replacement for V-714, which was taken through closure and scrapped after approval of the closure by OEPA. All the tanks will be used to store flammable spent solvents at least part of the time. All the tank systems are designed for flammable liquid storage. They meet NFPA guidelines.

#### a) Tanks V-114, V-214, V-314, V-414, V-514 and V-614:

These tanks were purchased by HCC and installed in 1969. They are vertical, cylindrical, flat bottom tanks of 10.5 feet diameter and are 24 feet high. Capacity for each of these tanks is 14,000 gallons.

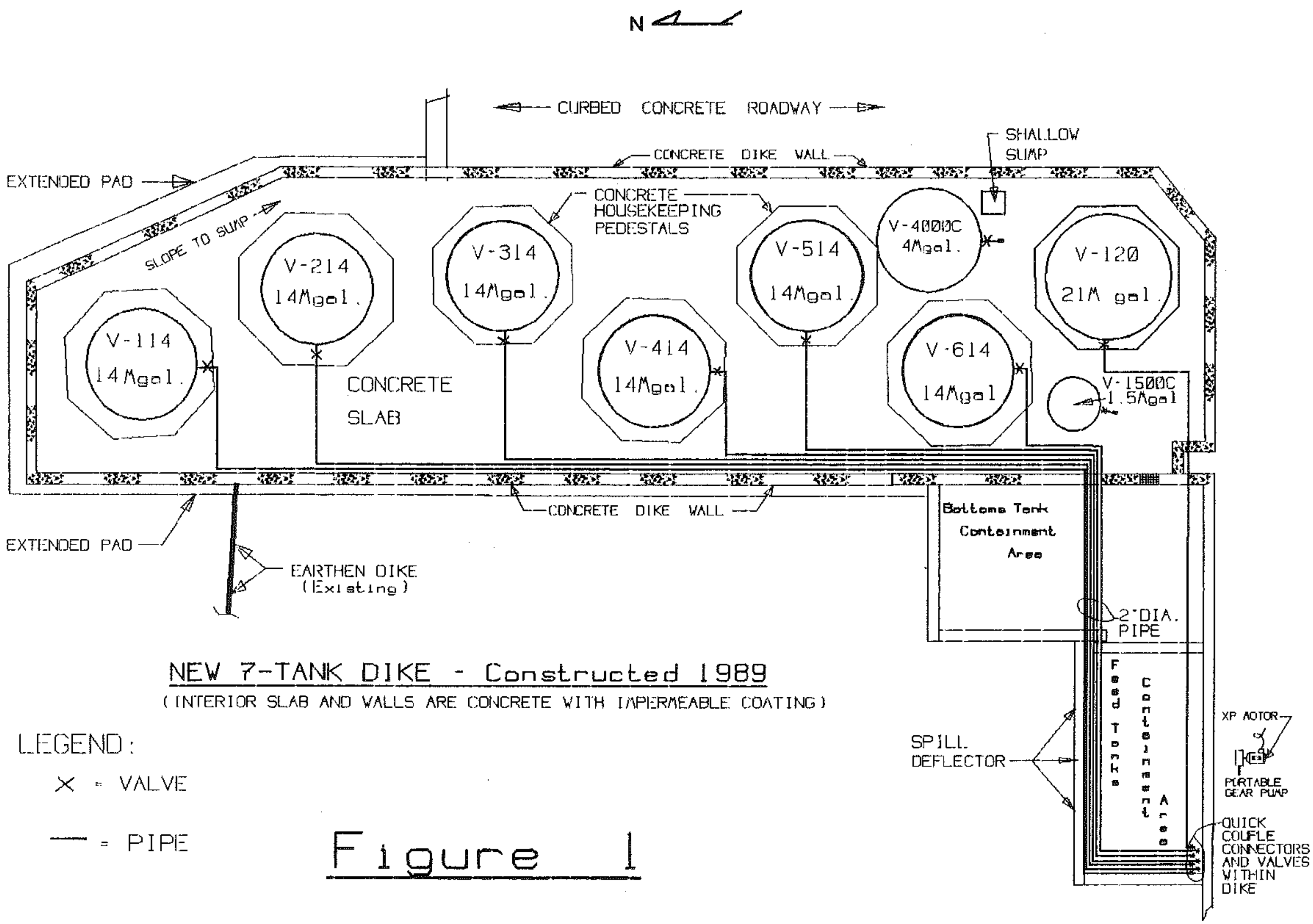
These six tanks are constructed of riveted plate, carbon steel with an original shell thickness of 3/8 inch.

The tanks operate at atmospheric pressure and are equipped with flame arrestors and conservation vents. Each tank is equipped with a high level probe connected to a high level alarm to prevent overfilling. Tank filling and emptying is manually controlled. Tank overflows are prevented with a manual shut-off system. Attachment D of Section D presents the description of the alarm system provided by the manufacturer, Princo Instruments, Inc. A float type level indicator shows the liquid level in each tank at any time. Each tank is grounded to prevent static electricity.

#### b) Tank V-120:

Tank V-120 was purchased used and placed in service in 1989. The tank was constructed in 1971 of welded 304 stainless steel plate with an original shell thickness of 3/16 inch. This vertical, cylindrical, flat bottom tank is 12 feet in diameter and 25 feet high with a capacity of 21,000 gallons.

Tank V-120 operates at atmospheric pressure and is equipped with a flame arrestor, conservation vent, high level alarm, float type level indicator and a manual shut-off system. The tank is grounded to prevent static electricity.




## NEW 7-TANK DIKE - Constructed 1989

(INTERIOR SLAB AND WALLS ARE CONCRETE WITH IMPERMEABLE COATING)

LEGEND:

X = VALVE

— = PIPE

# Figure 1

HUKILL CHEMICAL CORPORATION

\PARTB-10\PLOT0011.GCD Rev. 3/11/96

Scale: 1" = 14'

c) Tanks V-4000C and V-1500C (less-than-90-day storage tanks):

HCC purchased these tanks used. Tank V-4000C was constructed in 1979. The age of Tank V-1500C is estimated to be 20 years based on the installation date at HCC.

Both tanks have cone bottoms and are constructed of welded carbon steel plate. Tank V-4000C had an original shell thickness of 1/4 inch and cone thickness of 5/16 inch. V-4000C is equipped with an agitator. The original wall thickness of V-1500C is not known. Tank V-4000C has a volume of 4,000 gallons with a diameter of 10 feet and a height of 12 feet. Tank V-1500C has a volume of 1,500 gallons with a diameter of 5 feet and a height of 15 feet. Each of these tanks are supported on four steel legs welded to the tank. Refer to Appendix A for structural details for these less-than-90-day tanks.

Both of these tanks operate at atmospheric pressure and are equipped with flame arrestors, conservation vents and are grounded or bonded to prevent static electricity.

2. Ancillary Equipment

All the tank system piping is 2 inch diameter, Schedule 40, carbon steel. Piping connections are threaded couplings or unions and flanges. Valves are threaded body gate or ball valves with working pressure of at least 140 psig. Hoses are used to provide transfer options with a few portable pumps serving a large number of storage tanks. All hoses are either metal reinforced elastomer or all-metal (steel) flexible hoses with quick release OPW type fittings. Hoses and fittings are rated for at least 100 psig.

Hazardous waste is transferred to and from the tanks, except V-1500C and V-4000C, through the valved steel piping system. Piping is installed along the west wall of the dike and across the Feed/Bottoms Dike. A deflector has been installed along the north wall of the Feed/Bottoms Dike to assure that any spills would fall into the containment area. The valves at the end of the hoses are kept within the containment area. The two small tanks, V-1500C and V-4000C, use hoses as described above.

Portable, positive displacement pumps, designed to meet Class 1, Group D, Division 1 electrical rating, are used to transfer the waste from the tanker trucks to the spent solvent storage tanks. The pumps are located within spill containment pans adjacent to the containment area. Hoses with quick disconnect couplings are used to connect the piping to the pumps.

3. Secondary Containment

a) Description

**Figure 1**, found on page 5, shows the location of the tanks within the concrete containment dike, The Feed/Bottoms Tank Dike, west of the southern portion of the 7-

Tank Dike, is shown because the fill/discharge lines for each of the seven permitted tanks is routed across the top of the dike.

The secondary containment was completed in early 1989. The eastern section of the eight inch concrete slab was constructed as a roadway in November, 1988. The remainder of the dike slab and the containment walls were constructed in the Spring of 1989 to comply with the revised regulations for hazardous waste storage tank secondary containment.

Both the roadway and the containment dike bases, concrete thickness, strength and reinforcing were specified by S.M. Haw Associates. The dike was designed and constructed with the possibility of placing even larger tanks in it in the future. The designed specifications are included with the structural calculations in Appendix A of this exhibit. S.M. Haw was present during the construction of both the roadway slab and the containment dike to witness that the design was being followed by the contractor.

The tanks are set upon "housekeeping" pedestals to facilitate leak detection and to keep the tanks out of contained rainwater for most rainfalls.

It was mid-summer, 1989, when HCC was advised that above-ground containment was also required to have an impermeable coating. The dike was then coated with a chemical resistant polymer, "Siloxirane C2033", manufactured by Advanced Polymer Sciences, Inc. This coating was recommended by the manufacturer and passed HCC's testing. HCC's testing was half immersion of a sample coupon in a sealed bottle containing a mixture, by volume, of 80% methylene chloride and 20% acetone for greater than 24 hours without significant swelling, softening, weight gain or deterioration. The sample survived with less than 1 % weight gain, less than 1% increase in length, width or thickness and within 5 Shore Durometer D units and no apparent affect on the surface or color of the coating. The sample was in the same condition after 10 days. Most samples failed the 24-hour test.

The containment area slab to wall joints and the expansion joints are sealed with a chemical resistant polysulfide material, "CM-60" manufactured by W.R. Meadows, or equal. Specifications for the Siloxirane coating and the polysulfide material are presented in Attachment C of Section D.

The structural assessment calculations for both the slab and the containment wall are included in Appendix A of this exhibit. This dike was actually designed to contain 25,000 gallon storage tanks in the future.

The containment area concrete slab slopes to a one foot square, four inch deep concrete sump to facilitate removal of precipitation and spills. The containment area is inspected daily and accumulated precipitation and spills would be removed within 24 hours.

b) Containment Capacity

The spill containment for this dike is 5,258 cubic feet in addition to the volume reserved for the 25 year, 24 hour rainfall of 4 inches (1,081 cubic feet for the entire containment area including the wall area). The largest tank volume within the dike is V-120, which has a capacity of 21,000 gallons (2,807 cubic feet). This exceeds the containment requirements of OAC 3745-55-93(E)(1)(b). The calculations for this dike's containment capacity are found in Appendix B of this exhibit.

## DESIGN STANDARDS

1. Storage Tanks

V-114, V-214, V-314, V-414, V-514 and V-614 are riveted tanks and have no ASTM or UL designation. The tank walls have been ultrasonically tested by Professional Service Industries, Inc. The results of these wall thickness tests are found in Attachment B of this exhibit, with the structural references. There are no design standards available for the construction of these five storage tanks.

V-120 tank was designed and built to the 1968 A.S.M.E. Code for Unfired Vessels. It is Schedule 304 stainless steel, welded construction and was, apparently from the copy of the drawing, dye penetrant checked for leaks.

The design standards for tanks V-1500C and V-4000C are not available. These tanks have been in service at HCC's facility as less-than-90-day storage tanks for the last 15 years. These two tanks have also been ultrasonically tested and the resulting wall thickness results are found in Attachment B of Section D.

## WASTE COMPATIBILITY

The hazardous wastes stored in the subject tanks have the characteristics of Toxicity and Ignitability. The carbon and stainless steel tanks and ancillary equipment are compatible with the waste stored. The material used to coat the inside of the containment area was tested by both the manufacturer and HCC and found to be compatible with the constituents of the wastes to be stored in the system.

## CORROSION PROTECTION MEASURES

HCC has maintained a protective coat of paint on these tanks and on the supporting steel for the cone bottom tanks. As stated in the Waste Analysis Plan, the Acid Value or pH is obtained on incoming hazardous waste destined for this tank system. If the waste has the characteristic of Corrosivity, it will be neutralized prior or during transfer to the storage tank. HCC also periodically has the thickness of the storage tanks measured by an outside testing service to be sure that the tank thickness is within safe operating limits.

These tanks will not be in contact with the soil or water. The housekeeping pedestals will normally keep the tanks out of rainwater collected in the dike. Therefore, the requirements of OAC 3745-55-92(A)(3) do not apply to this system.

## STRUCTURAL ASSESSMENTS

1. Tanks

Appendix A of this exhibit contains the structural calculations for the four styles of tanks in this dike. The previous calculations for the 14,000 gallon tanks were done in 1984 through 1986 for the early revisions of HCC's Part B application. Based on the recent request by OEPA, HCC has contracted to have all the structural analysis redone by S.M. Haw Associates. Please note that the structural calculations are grouped by type of tank in the Appendix A of this exhibit. The page numbering starts over for each type of tank.

The "service factor" is defined as the actual minimum thickness measurement divided by the calculated minimum thickness. The calculated minimum thickness includes the allowable working stress of the material. I. e., a service factor of 1.0 represents a tank shell loaded to its full allowable stress.

The minimum measured shell thickness for the V-114 to V-614 tanks provides a service factor of 4.1 per page 3 of Appendix A. The V-114 to V-614 tanks will be taken out of service when the service factor reaches 1.5 (0.0954 inches) or when pinhole leaks begin appearing.

Appendix A also demonstrates the structural safety of the riveted tanks, V-114 to V-614.

The minimum measured shell thickness of the V-120SS tank provides a service factor of 2.4. This tank will be taken out of service when the service factor reaches 1.5 (0.1262 inches) or when pinhole leaks begin appearing.

The minimum measured shell thickness of the V-4000C tank provides a service factor of 9.57 for the shell and 6.06 for the cone. This tank will be taken out of service when the service factor reaches 1.5 ( 0.0350 inches for the shell or 0.0698 inches for the cone) or when pinhole leaks begin appearing.

The minimum measured shell thickness of the V-1500C tank provides a service factor of 8.33 for the shell and 4.85 for the cone. This tank will be taken out of service when the service factor reaches 1.5 (0.0257 inches for the shell or 0.036 inches for the cone) or when pinhole leaks begin appearing.

a.) Seismic Considerations

The seismic considerations calculate the forces applied to a fully loaded tank according to the guidelines of the Ohio Basic Building Code.

The calculations in Appendix A demonstrate that the factor of safety is 16.9 for seismic considerations for the V-114 to V-116 tanks.

The calculated factor of safety for the V-120SS tank is 18.3.

The calculated factor of safety for the V-4000C tank is 6.1.

The calculated factor of safety for the V-1500C tank is 2.7.

b.) Wind Considerations

The seismic considerations calculate the forces applied to a fully loaded tank according to the guidelines of the Ohio Basic Building Code.

The calculated factor of safety against wind overturning is 1.7 for V-114 to V-614 tanks.

The calculated factor of safety against overturning from wind forces for the V-120SS tank is 1.54.

The calculated factor of safety against overturning from wind forces for the V-4000C tank is 3.0.

The calculated factor of safety against overturning from wind forces for the V-1500C tank is 0.8. As noted in the structural engineer's calculations, this tank must be braced or anchored to resist wind forces.

c.) Frost Heave

The calculated factor of safety against overturning the tanks in a high wind with frost heave elevating one side of the V-114 to V-614 tanks is calculated to be 1.68.

The calculated factor of safety against overturning in high wind with frost heave elevating one side of the V-120SS tank is calculated to be 1.5

The calculated factor of safety against overturning in a high wind with frost heave elevating one side of the V-4000C tank is calculated to be 2.98.

The calculated factor of safety against overturning in a high wind with frost heave elevating one side of the V-1500C tank is calculated to be 0.76. As noted above in the "Wind Considerations" section, this tank must be braced or anchored.

2. Foundations

a.) Full Tanks

The V-114 to V-614 tanks help create a bearing pressure on the soil of 2,257 pounds per square foot (psf). The existing soil capacity is 4,000 psf. We used 1.33 specific gravity, which is 11.09 lb./gal. or 82.98 lb./cu.ft., as the maximum density for liquids to be stored in all spent solvent storage tanks.

V-120SS tank soil pressure was calculated to be 2,338 psf with existing soil bearing pressure at 4,000 psf.

V-4000C tank leg soil pressure was calculated to be 2,456 psf. with existing soil bearing pressure of 4,000 psf.

V-1500C tank leg soil pressure was calculated to be 1,443 psf. with existing soil bearing pressure of 4,000 psf.

3. Secondary Containment

The requirement that the dike walls be structurally capable of containing the spill of the largest tank plus the 25 year, 24 hour rainfall of four inches has been demonstrated. The calculations are provided in Appendix A of this exhibit. The factor of safety for the dike wall is 6.1 for containing a full dike of liquid with a specific gravity of 1.33.

*Form No. TA/WA-02*

**Certification Statement for Written Assessment for the Design of the Tank System**

I attest that I am an independent, qualified, registered professional engineer.

I have reviewed the attached Seven -Tank Dike System written assessment and I attest in writing that the tank system has sufficient structural integrity and is acceptable for the storage of hazardous waste.

The assessment shows that the foundation, structural support, seams, connections, and pressure controls are adequately designed and that the tank system has sufficient structural strength, compatibility with the waste(s) to be stored or treated and corrosion protection to ensure that it will not collapse, rupture, or fail.

The assessment includes, at a minimum, the following information:

(1) Design standards according to which tank(s) and/or the ancillary equipment are constructed,

(2) Hazardous characteristics of the waste(s) to be handled,

(3) For new tank systems or components in which the external shell of a metal tank or any external metal component of the tank system will be in contact with the soil or with water, a determination by a corrosion expert of:

(a) Factors affecting the potential for corrosion,
(b) The type and degree of external corrosion protection that are needed to ensure the integrity of the tank system during the use of the tank system or components,

(4) Design considerations to ensure that:

(a) Tank foundations will maintain the load of a full tank, and
(b) Tank system will withstand the effects of frost heave.

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of ~~fine and~~ imprisonment for knowing violations.

STATE OF OHIO
STANLEY
M.
HAW
24218
REGISTERED
PROFESSIONAL ENGINEER

Professional Seal

Stanley M. Haw

Signature of the Registered Professional Engineer

## TANK SYSTEM INTEGRITY EXAMINATION

1. External Inspection

An external inspection of this tank system and its components was completed by S.M. Haw Associates, Inc. in December, 1995. The tank system was in operation and there were no signs of weld breaks, punctures, coating failure, cracks or corrosion. There were no leaks at fittings, access manways, rivets or welds, valves or piping. HCC has installed additional piping supports inside the dike to meet the recommended maximum span of ten feet for the 2 inch diameter pipe. The ancillary pipes, valves and fittings appear to be well supported, protected and free of leaks.

The concrete slab, dike walls and pedestals were clean and free of visible spills. The concrete joints were sealed with caulking and were also taped with fiberglass and coated. There were minor surfacial cracks in the fiberglass tape, but they did not appear to affect the containment integrity of the system.

2. Non-Destructive Testing

Ultrasonic thickness measurements were made on all nine tanks within this dike in June, 1994. The results of these tank wall thickness measurements are provided in the references, Attachment B of Section D.

3. Tightness Testing

No further tightness testing should be required at this time, since this system is presently in operation and there are no leaks of the tanks.

4. Ancillary Equipment

The pipes, valves and fittings comprise the ancillary equipment. Portable positive displacement gear pumps are used to transfer the hazardous waste in most cases. Quick couple connectors, high pressure rated hoses and Schedule 40 carbon steel pipe comprise the remainder of the "system". Catch pans are used to contain waste drippings when uncoupling lines to or from transport trailers. As stated above, there are no leaks or evidence of leaks and the ancillary equipment appears to be in good condition.

5. Installation Certification

These tanks were relocated prior to the system being judged a "New System." There was no registered tank installation inspector or registered professional engineer on-site to supervise the installation. The following installation certification is not signed for this reason.

It should be noted that Mr. Robert Lang, an employee of Hukill Chemical Corporation for 29 years at the time, supervised the installation of all tanks.

One of the 14,000 gallon tanks being relocated, V-714, was inspected and did not pass inspection. It was immediately taken out of service and then taken through closure, which was approved by the Ohio EPA.

These tanks are above ground, within a concrete containment area and resting on pedestals or legs. The piping system is within the concrete containment dike and easily inspected.

The installation inspection items referring to the placement, backfilling and corrosion due to contact with soil and/or water are not applicable to this installation.

*Form No. TA/WA-03*

**Certification Statement for the Installation of the Tank System**

I attest that I am an independent, qualified, installation inspector or an independent, qualified, registered professional engineer, who is trained and experienced in the proper installation of tank systems or components.

I have supervised the installation of the tank system Seven-Tank Dike System, February, 1989, and I attest that proper handling procedures were adhered to in order to prevent damage to the system during installation, and that the tank system was properly installed and that repairs pursuant to the installation activities (1) and (3) were performed.

The installation included the following activities:

(1) Prior to covering, enclosing, or placing a new tank system or component in use, I have inspected the system for the presence of any of the following items:

(a) Weld Breaks
(b) Punctures
(c) Scrapes of protective coatings,
(d) Cracks
(e) Corrosion, and
(f) Other structural damage or inadequate construction/installation,

and that all the discrepancies were remedied before the tank system was covered, enclosed, or placed in use.

(2) New tank systems or components that were placed underground and that were backfilled were provided with a backfill material that is noncorrosive, porous, homogenous substance and that was installed so that the backfill was placed completely around the tank and compacted to ensure that the tank and piping are fully and uniformly supported.

(3) All new tanks and ancillary equipment were tested for tightness prior to being covered, enclosed, or placed in use. If a tank system was found not to be tight, all repairs necessary to remedy the leak(s) in the system were performed prior to the tank system being covered, enclosed, or placed into use.

(4) Ancillary equipment were supported and protected against physical damage and excessive stress due to settlement, vibration, expansion, or contraction.

(5) The piping installation procedures described in "American Petroleum Institute (API)" publication 1615 (November 1979), "Installation of Underground Petroleum Storage Systems," or ANSI standard B31.4, "Liquid petroleum

Transportation Piping System," were used (where applicable) as guidelines for proper installation of piping systems.

(6) For new tank systems or components in which the external shell of a metal tank or any external metal component of the tank system will be in contact with the soil or with water, the owner or operator has provided corrosion protection recommended by an independent corrosion expert, based on the following information:

(a) Factors affecting the potential for corrosion,
(b) The type and degree of external corrosion protection that are needed to ensure the integrity of the tank system during the use of the tank system or components,

(7) The installation of a corrosion protection system that was field-fabricated was supervised by an independent corrosion expert to ensure proper installation.

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Professional Seal

Signature of the Installation Inspector or Registered Professional Engineer

Not Signed, Refer to previous page.

# APPENDIX A

# STRUCTURAL CALCULATIONS

# Structural Assessment of a Hazardous Waste Storage Tank
## for Hukill Chemical Company

*by S. M. Haw Associates, Inc.*

*Professional Engineers*

December 8, 1995

**1. Description** [A]

*Hazardous Waste Dike Identification*: .....7 Tank Dike System
*Tank Designation*:...................................V-114, V-214, V-314, V-414, V-514, V-614
*Rated Capacity*:........................................14,000 Gallons each tank
*Specific Gravity of Contained Liquid*: .....1.33 (maximum use)
*Part B Application, Section D Location*: .Exhibit D-2
*Tank Construction*: .Vertical, riveted carbon steel plate with flat bottom and full bearing [1.1]
*Design Standard:* .............None
*Material Specifications*:...Shell, Assumed minimum ASME SA 515 Grade 55 carbon steel [2.1]
*Tank Dimensions*: ........Cyl. Shell Height: 23'-10 1/2" Shell Diameter (O.D.): 10'-7 1/8" [1.1]
Shell Thickness (Assumed): 1/4"
Shell Top (Assumed): 3/16"
Shell Bottom (Assumed): 1/4"
*Tank Shell Thickness Measurements:* Minimum measured shell, lower: 0.250 inches [3.1]
Minimum measured shell, bottom: 0.263 inches

**2. Weight of Tank Shell**

Cylindrical Shell Area: $A = \pi \times d \times h$ [4]
$= 3.1416 \times 10.59 \times 23.88 = 794.5$ sq. ft
Cylindrical Shell Weight: $Wt = A \times (\text{pl. wt.})$ [8.1]
$= 794.5 \times 10.2$ lbs./sq. ft.(1/4") = 8,104 lb

Top Area: $A = \pi \times d^2/4$ [5]
$= 3.1416 \times 10.59 \times 10.59 / 4 = 88.1$ sq. ft.
Top Weight: $Wt = A \times (\text{pl. wt.})$ [8.1]
$= 88.1 \times 7.66$ lbs./sq. ft. (3/16") = 675 lb

Bottom Area: $A = \pi \times d^2/4$ [5]
$= 3.1416 \times 10.59 \times 10.59 / 4 = 88.1$ sq. ft.
Bottom Weight: $Wt = A \times (\text{pl. wt.})$ [8.1]
$= 88.1 \times 10.2$ lbs./sq. ft. (1/4") = 899 lb

Weight of Miscellaneous Appurtenances: 500 lb

TOTAL WEIGHT OF TANK: 10,178 lb

**3. Weight of Contained Liquid**

Volume of cylinder: $V = \pi \times {d^2}/{4} \times ht$ [4]

$= \pi \times 10.55^2 \times 23.88 = 2{,}088$ cu. ft.

$d = 10'\text{-}7\ 1/8" - (2 \times 0.238") = 10.55$ ft.

Weight of liquid: $Wgt = Vol \times 62.4 \times sp.\ gr.$

$= 2088 \times 62.4 \times 1.33 =$ 173,287 lb

**4. Tank Supports**

Tank is full bottom bearing on concrete slab.

Total Weight Tank & Liquid: 10,178 lb + 173,287 lb = 183,465 lb

Area of bottom: 88.1 sq. ft.

Force on Base: $\frac{P(lb)}{A(sq.ft.)} = \frac{183{,}465}{88.1} = 2{,}082$ lb/sq. ft.

**5. Calculation of Required Tank Wall Thickness -- Cylindrical Shell**

A. Shell Tension

$T_h = 2.60 \times h \times D \times g$ [11-eq. 3]

$T_h$ = Shell Tension, at depth h (lbs per inch)
h = Depth from top of tank (ft.)
D = Diameter of tank (ft.)
g = Specific gravity of contained liquid

At h = 11'-8" from top of tank

$T_h = 2.60 \times 11'\text{-}8" \times 10.55 \times 1.33 = 426$ lbs/in.

At h = 23'-10 1/2" from top of tank

$T_h = 2.60 \times 23.88 \times 10.55 \times 1.33 = 871$ lbs/in.

B. Minimum Shell Thickness

$t_h = T_h / (f \times E)$ [11-eq. 4]

$t_h$ = Minimum required shell plate thickness (inches)
$T_h$ = Shell Tension, at depth h (lbs per inch)
f = Allowable unit stress (13,700 psi) [2.1]
E = Joint efficiency (1.0 @ shell plate)

At h = 23'-10 1/2" from top of tank
$t_h = 871 / (13{,}700 \times 1.0) = 0.0636$ in.
Minimum measured thickness = 0.263 in.

Service Factor (SF) = $\dfrac{t_{actual}}{t_{required}} = \dfrac{0.263}{0.0636} = 4.1$ ∴ The cylindrical shell is OK

C. Shear in Rivets [10]
At h = 11'-8" from top of tank -- Rivets spaced at 2" centers
$P_s = T_h \times w$

$P_s$ = Force in a strip containing one rivet (lbs)
$T_h$ = Shell Tension (lbs per inch)
w = Spacing of rivets and width of strip (inches)

$P_s$ = 426 lbs /inch × 2" = 852 lbs

Allowable load for one rivet (ASTM A502-1 steel) in single shear = 7,700 lbs [ 9]
Allowable load on 2" strip of solid shell plate = 2" lb × 0.238" × 13,700 psi = 6,521 lbs
Allowable load shell plate at rivet = (2"-13/16") × 0.238" × 13,700 psi = 3,872 lbs
Joint Efficiency = (Strength of Joint) / (Strength of Solid Plate) = 3,872/6,521 = 0.59
Service Factor (SF) = Joint strength / Joint load = 3,872 / 852 = 4.50 O.K.

D. At h = 23'-10 1/2" from top of tank
2 rows of rivets, each row spaced at 2 3/4", staggered with the other row, 1 1/2"
$P_s = T_h \times w$

$P_s$ = Force in a strip containing three rivets (lbs)
$T_h$ = Shell Tension (lbs per inch)
w = Width of strip (inches)

$P_s$ = 871 lbs /inch × 4 1/8" = 3,593 lbs

Allowable load for 3 rivets (ASTM A502-1 steel) in single shear = 7,700 × 3 = 23,100 lbs [ 9]
Service Factor (SF) of rivets = Rivet strength / $P_s$ load = 23,100 / 3,593 = 6.43 OK

Allowable load on 4 1/8" strip of solid shell plate = 4 1/8" × 0.263" × 13,700 psi = 14,863 lbs
Service Factor (SF) of solid plate = Plate strength / $P_s$ load = 14,863 / 3,593 = 4.14 OK

E. Net area of shell plate through 2 rivets [10]

$A_{net\text{-}2} = t\,(w - (2d))$ [12]

$A_{net\text{-}2}$ = Net area thru 2 rivets (sq. in.)
t = Net plate thickness (in.)
w = Width of strip (in.)
d = Gross diameter of hole (nominal rivet diameter + 1/16") (inches) [12]

$A_{net\text{-}2} = 0.263 \times (4\ 1/8 - (2 \times 13/16)) = 0.658$ sq. in.

F. Net area of shell plate through 3 rivets [10]

$A_{net\text{-}3} = t\,(w - (3d) + 2s^2/4g)$ [12]

$A_{net\text{-}3}$ = Net area thru 3 rivets (sq. in.)
s = Longitudinal spacing (pitch) of any two consecutive holes (in.)
g = Transverse spacing (gage) between rivet gage lines (in.)

$A_{net\text{-}3} = 0.263 \times (4\ 1/8 - (3 \times 13/16) + 2 \times (1\ 1/2)^2/(4 \times 1\ 3/8)) = 0.659$ sq. in. (controls)
Allowable strength of plate = $A_{net\text{-}3}$ × allowable stress in plate = 0.659 × 13,700 = 9,023 lbs.
Service Factor (SF) of plate thru 3 rivets=Plate strength/$P_s$ load = 9,028 / 3,593 = 2.51 OK

G. Edge distance check

$ED = 2P/F_u t$ [13]

ED = Minimum edge distance, center of rivet to edge of plate (in.)
P = Load on one rivet (lbs)
Fu = Ultimate tensile stress in plate (lbs/sq in.) [9]
t = Thickness of the plate (in.)

ED = 2 × 7,700/(17,500 × 0.263) = 0.88"
Tanks were built with 1" edge distance which is OK.

## 6. Calculation of Seismic Forces on the Tank

A. Seismic Formula -- Seismic Zone #1 (Ohio) [Ohio Basic Building Code = OBBC]

$V = 2.5\,A_v\,I\,K\,C\,S\,W$ [OBBC 1113.4]

V = Lateral Seismic Force (lbs)
$A_v$ = 0.075 (Coefficient for Ohio) [OBBC 1113.4.1]
I = Importance Factor (For industrial plants, I = 1.0) [OBBC 1113.4.2]
K = Horizontal Force Factor (For a tank on ground, K = 1.0) [OBBC 1113.4.3] [& OBBC 1113.9.3]
C S = Coefficient combination (For zones 0, 1 & 2, CS = 0.14) [OBBC 1113.4.4]
W = Weight of the fully loaded tank (lbs)

V = 2.5 × 0.075 × 1.0 × 1.0 × 0.14 × (10,178 lbs + 173,287 lbs) =4,816 lbs

B Overturning Moment Due to Seismic Force

OTM = V /1000 × arm

OTM = Overturning Moment about base (ft. kips)
arm = Vertical Distance from the base to center of gravity of loaded tank(ft.)

OTM = 4,816 lbs/1000 lbs/kip × (23'-10 1/2")/2 = 57.5 ft. kips

C. Resisting Moment of the Tank -- Full Tank

RM = W /1000 × delta

RM = Resisting Moment (ft. kips)
delta = Horizontal Distance from the center of the tank to its overturning point (ft.)

RM = (10,178 lbs + 173,287 lbs) /1000 lbs /kip × (10'-7 1/8") /2 = 971.8 ft. kips

D. Factor of Safety Against Seismic Overturning

Factor of Safety (FOS) = RM / OTM = 971.8 / 57.5 = 16.9

Since FOS is greater than 1.5, tank is safe against overturning from seismic forces.

**7. Calculation of Wind Forces on the Tank** [Ohio Basic Building Code = OBBC]

A. Wind Formula -- 80 mph wind zone -- Exposure B

$P_d = P_e \times I^2 \times C_p$ [OBBC 1112.3]

Definitions as follows: [OBBC 1112.2]

$P_d$ = Design Wind Pressure (lbs per sq. ft.)
$P_e$ = Effective Velocity Pressure - Exposure B ($P_e$ = 13psf) [OBBC Table 1112.3.3a ]
I = Importance Factor for Service (I = 1.0) [OBBC Table 1112.2a(1)]
$C_p$ = External Pressure Coefficient for Round Tanks [OBBC Table 1112.2d ]
For h/D = 23'-10 1/2" / 10'-7 1/8" = 2.25, $C_p$ = 0.8

$P_d = 13 \times (1.0)^2 \times 0.8 = 10.4$ psf

B. Wind Force on Tank

$P = P_d \times$ Wind Area

Wind Area = D × h = 10'-7 1/8" × 23'-10 1/2" = 252.9 sq. ft.
D = Tank Diameter (ft.)
h = Tank Height (ft.)

P = 10.4 × 252.9 = 2,630 lbs.

C. Overturning Moment due to Wind Force

OTM = P /1000 × arm

arm = Vertical Distance from the base to center of gravity of the wind area (ft.)

OTM = 2,630 lbs /1000 lbs/kip × (23'-10 1/2") /2 = 31.4 ft. kips

D. Resisting Moment of Tank -- Empty Tank

RM = DL / 1000 × delta

RM = Resisting Moment (ft. kips)

DL = Dead Load of Tank (Weight of empty tank) (lbs)

delta = Horizontal Distance from center of tank to its overturning point (diam /2)

RM = 10,178 lbs /1000 lbs/kip × (10'-7 1/8") /2 = 53.9 ft. kips

E. Factor of Safety Against Wind Overturning

Factor of Safety (FOS) = RM / OTM = 53.9 / 31.4 = 1.7

Since FOS is greater than 1.5, tank is safe against overturning from wind forces.

**8. Frost Heave** [14.1]

Maximum frost design depth per local Building Code in this area is 30 inches.

Assuming the underlaying soil is completely saturated with water and had frozen solid and using an expansion factor of water to ice as 10%, the frozen area would rise 30 inches x 0.10 or 3 inches above an unfrozen area.

The tanks of this dike system all set directly upon an 8 inch thick reinforced concrete slab-on grade, 30'-0" wide x 111'-3"long.

Assuming the maximum condition where the narrow side of the slab-on-grade has 30 inches of water under it, and the other side has 30 inches of ice, the differential due to frost heave would be 3 inches vertical movement in 30'-0" horizontal distance.

# Structural Assessment of a Hazardous Waste Storage Tank for Hukill Chemical Company

## 7 Tank Dike System - Tanks V-114 thru V-614

A. Proportion to find differential elevation of base:

$$\frac{V}{H}=\frac{Y}{h}$$

V = Vertical movement of slab (inches)
H = Horizontal length of slab (ft.)
Y = Vertical rise of tank edge (inches)
h = Horizontal distance between tank edges,
  diameter of tank (ft.)

Y = (V/H) x (h)
 = (3" / 30'-0") x (10'-7 1/8") = 1.0594 inch vert. rise

B. Proportion to find resulting offset of Center of Gravity of tank:

$$\frac{Y}{h}=\frac{X}{d}$$

X = Horizontal offset distance to center of tank (inches)
d = Vertical distance from base to center of tank (ft.)

X = (Y/h) x (d)
 = (1.0594" / 10'-7 1/8") x (23'-10 1/2")/2 = 1.1938 in. = 0.0995 ft.

C. Calculate resulting Frost Resisting Moment:
FRM = DL x delta

FRM = Frost Resisting Moment (ft. kips)
DL = Dead Load of Tank (Weight of empty tank) (lbs)
delta = Horizontal Distance from center of tank to its overturning point (ft.)

FRM = 10,178 lbs/1000 lbs/kip x [(10'-7 1/8") /2 - 0.0995] = 52.90 ft. kips

D. Overturning Moment due to Wind Force [para. 7.C.]
OTM = 31.4 ft. kips

E. Factor of Safety Against Overturning:
Factor of Safety (FOS) = FRM/OTM = 52.9/31.4 = 1.68 > 1.5
OK

**9. Foundation Investigation** [14.1]

The bottom of the containment area is a reinforced concrete slab, 8 inch minimum thickness.

| | |
|---|---|
| Total weight of a fully loaded tank produces a base pressure of | 2,082 psf |
| The 6" house keeping pad produces a pressure of (6"/12" × 150 lbs/cu. ft.) | 75 psf |
| The 8" base slab produces a pressure of (8"/12" × 150 lbs/cu. ft.) | 100 psf |
| Total soil pressure under each tank | 2,257 psf |

Existing soil bearing [21]

Allowable soil bearing capacity 4,000 psf

The concrete base slab and the soil capacity is adequate to carry the tanks

**10. Containment Wall Investigation**

A. Construction [14.1]

Reinforced concrete wall, doweled to the base slab
12" wide by 3'-0" high
Vertical reinforcing consists of #4 bars at 18" on centers, both faces
Horizontal reinforcing consists of #4 bars at 14" on centers, both faces

B. Wall Design [18]

$P = 1/2\, w\, h^2$

P = Force on wall due to the contined liquid pressure (lbs per ft. of length)
w = Weight of contained liquid (lbs / cubic ft.)
h = Height of contained liquid (ft.)

$P = 1/2\,(62.4 \times 1.33) \times (3'\text{-}0'')^2 = 373.5$ lbs / ft.

$M = 1/3\, P\, h$

M = Moment at base of wall (ft. lbs / ft.)
P = Force on wall (lbs / ft.)
h = Height of contained liquid (ft.)

$M = 1/3 \times 373.5 \times 3'\text{-}0'' = 373.5$ ft. lbs / ft or 0.374 ft. kips / ft.

$RM = A_s\, a\, d$ [Simplified concrete beam design function -- ]
[American Concrete Institute publication -- ACI SP-3]

RM = Resisting Moment at base of wall (ft. lbs / ft.)
$A_s$ = Area of reinforcing steel (sq. inches / ft.) -- (for #4 @ 18", $A_s = 0.13$) [15]
a = Coefficient of concrete design (for 24 ksi steel and 3 ksi concrete use 1.76) [16]
d = Distance from face of wall to centerline of far reinforcing bar.

$RM = 0.13 \times 1.76 \times (12''\text{-}2'') = 2.29$ ft. kips / ft.

C. Factor of Safety of Containment Wall

Factor of Safety (FOS) = RM / M = 2.29 / 0.374 = 6.1

Since FOS is greater than 1.0, wall will safely contain the full height of 1.33 s.g. fluid.

Structural Assessment of a Hazardous Waste Storage Tank
for Hukill Chemical Company

*by S. M. Haw Associates, Inc.*
*Professional Engineers*

November 10, 1995

**1. Description** [A]

*Hazardous Waste Dike Identification*: .....7 Tank Dike System
*Tank Designation*: ....................................V-120 SS
*Rated Capacity*: .........................................21,000 Gallons
*Specific Gravity of Contained Liquid*: .....1.33 (Maximum Use)
*Part B Application, Section D Location*: .Exhibit D-2
*Tank Construction*: .Vertical, welded stainless steel plate with bottom bearing [1.2]
*Design Standard:* ...............................1968 A.S.M.E. Code Unfired Vessels [1.2]
*Material Specifications*: ...Shell, ASME SA 240 Grade 304 Stainless Steel [2.2]
*Tank Dimensions*: Cyl. Shell Height: 25'-0" Shell Diameter (I.D.): 12'-0" [1.2]
Shell Top Thickness (Design): 3/16" [1.2]
Shell Thickness (Design): 3/16"
Bottom Thickness (Design): 1/4"

*Tank Shell Thickness Measurements:* Minimum measured shell, top: 0.202 inches [3.6]
Minimum measured shell, upper: 0.208 inches
Minimum measured shell, middle: 0.203 inches
Minimum measured shell, lower: 0.202 inches
Minimum measured shell, bottom: 0.205 inches

**2. Weight of Tank Shell**

Cylindrical Shell Area: $A = \pi \times d \times h$ [4]
$= 3.1416 \times 12.0 \times 25.0 = 942.5$ sq. ft
Cylindrical Shell Weight: $Wt = A \times (\text{pl. wt.})$ [8.2]
$= 942.5 \times 7.87$ lbs./sq. ft. (3/16") = 7,417 lb

Top Area: $A = \pi \times d^2/4$ [5]
$= 3.1416 \times 12.0^2 / 4 = 113.1$ sq. ft.
Top Weight: $Wt = A \times (\text{pl. wt.})$ [8.2]
$= 113.1 \times 7.87$ lbs./sq. ft. (3/16") = 890 lb

Bottom Area: $A = \pi \times d^2/4$ [5]
$= 3.1416 \times 12.0^2 / 4 = 113.1$ sq. ft.
Bottom Weight: $Wt = A \times (\text{pl. wt.})$ [8.2]
$= 113.1 \times 10.49$ lbs./sq. ft. (1/4") = 1186 lb

Weight of Miscellaneous Appurtenances: 500 lb

TOTAL WEIGHT OF TANK: 9,993 lb

**3. Weight of Contained Liquid**

Volume of cylinder: $V = \pi \times {d^2}/{4} \times ht$ [4]

$= \pi \times 12.0^2 /4 \times 25.0 = 2{,}827$ cu. ft.

Weight of liquid: $Wgt = Vol \times 62.4 \times sp.\ gr.$

$= 2827 \times 62.4 \times 1.33 =$ 234,618 lb

**4. Tank Support**

Tank is full bottom bearing on concrete slab.

Total Weight of Tank & Liquid: 9,993 lb + 234,618 lb = 244,611 lb

Area of bottom: 113.1 sq. ft.

Force on Base: $\frac{P}{A} = \frac{244{,}611}{113.1}$ =2,163 lb/sq. ft.

P = Total Weight
A = Area of Base

**5. Calculation of Required Tank Wall Thickness -- Cylindrical Shell**

$$t_h = \frac{2.60 \times h \times d \times g}{f \times E}$$ [11 - eq 3]

$t_h$ = Minimum required shell plate thickness (inches)
h = Depth from top of tank (feet)
d = Diameter of tank (ft.)
g = Specific gravity of contained liquid
f = Allowable unit stress (18,700 psi) [2.2]
E = Joint efficiency factor (0.66) [11 - Table 1]

$$t_h = \frac{2.60 \times 25.0 \times 12.0 \times 1.33}{18{,}700 \times 0.66} = 0.0841 \text{ inches}$$

Minimum measured thickness = 0.202

Service Factor (SF) = $\frac{t_{actual}}{t_{required}} = \frac{0.202}{0.0841} = 2.40$

Conclusion: The cylindrical shell is OK

**6. Calculation of Seismic Forces on the Tank**

A. Seismic Formula -- Seismic Zone #1 (Ohio) [Ohio Basic Building Code = OBBC]

$V = 2.5\ A_v\ I\ K\ C\ S\ W$ [OBBC 1113.4]

$V$ = Lateral Seismic Force (lbs)
$A_v = 0.075$ (Coefficient for Ohio) [OBBC 1113.4.1]
$I$ = Importance Factor (For industrial plants, $I = 1.0$) [OBBC 1113.4.2]
$K$ = Horizontal Force Factor (For a tank on ground, $K = 1.0$) [OBBC 1113.4.3] [& OBBC 1113.9.3]
$C\ S$ = Coefficient combination (For zones 0, 1 & 2, $CS = 0.14$) [OBBC 1113.4.4]
$W$ = Weight of the fully loaded tank (lbs)

$V = 2.5 \times 0.075 \times 1.0 \times 1.0 \times 0.14 \times (9{,}993 \text{ lbs} + 234{,}618 \text{ lbs}) = 6{,}421 \text{ lbs}$

B Overturning Moment Due to Seismic Force

$OTM = V / 1000 \times arm$
OTM = Overturning Moment about base (ft. kips)
arm = Vertical Distance from the base to center of gravity of loaded tank(ft.)

$OTM = 6{,}421 \text{ lbs}/1000 \text{ lbs/kip} \times (25'\text{-}0'')/2 = 80.3$ ft. kips

C. Resisting Moment of the Tank -- Full Tank

$RM = W / 1000 \times delta$
RM = Resisting Moment (ft. kips)
delta = Horizontal Distance from the center of the tank to its overturning point (ft.)

$RM = (9{,}993 \text{ lbs} + 234{,}618 \text{ lbs}) / 1000 \text{ lbs /kip} \times (12'\text{-}0'') / 2 = 1{,}467.7$ ft. kips

D. Factor of Safety Against Seismic Overturning

Factor of Safety (FOS) $= RM / OTM$
$= 1{,}467.7 / 80.3 = 18.3$

Since FOS is greater than 1.5, tank is safe against overturning from seismic forces.

**7. Calculation of Wind Forces on the Tank** [Ohio Basic Building Code = OBBC]

A. Wind Formula -- 80 mph wind zone -- Exposure B

$P_d = P_e \times I^2 \times C_p$ [OBBC 1112.3]

Definitions as follows: [OBBC 1112.2]

$P_d$ = Design Wind Pressure (lbs per sq. ft.)

$P_e$ = Effective Velocity Pressure - Exposure B ($P_e$ = 13psf) [OBBC Table 1112.3.3a ]

I = Importance Factor for Service (I = 1.0) [OBBC Table 1112.2a(1)]

$C_p$ = External Pressure Coefficient for Round Tanks [OBBC Table 1112.2d ]

For h/D = 25'-0" / 12'-0" = 2.08, $C_p$ = 0.8

$P_d = 13 \times (1.0)^2 \times 0.8 = 10.4$ psf

B. Wind Force on Tank

$P = P_d \times$ Wind Area

Wind Area = D × h = 12'-0" × 25'-0" = 300.0 sq. ft.

D = Tank Diameter (ft.)

h = Tank Height (ft.)

P = 10.4 × 300.0 = 3,120 lbs.

C. Overturning Moment due to Wind Force

OTM = P /1000 × arm

arm = Vertical Distance from the base to center of gravity of the wind area (ft.)

OTM = 3,120 lbs /1000 lbs/kip × (25'-0") /2 = 39.0 ft. kips

D. Resisting Moment of Tank -- Empty Tank

RM = DL / 1000 × delta

RM = Resisting Moment (ft. kips)

DL = Dead Load of Tank (Weight of empty tank) (lbs)

delta = Horizontal Distance from center of tank to its overturning point (diam /2)

RM = 9,993 lbs /1000 lbs/kip × (12'-0") /2 = 60.0 ft. kips

E. Factor of Safety Against Wind Overturning

Factor of Safety (FOS) = RM / OTM = 60.0 / 39.0 = 1.54

Since FOS is greater than 1.5, tank is safe against overturning from wind forces.

**8. Frost Heave** [14.1]

Maximum frost design depth per local Building Code in this area is 30 inches.

Assuming the underlaying soil is completely saturated with water and had frozen solid and using an expansion factor of water to ice as 10%, the frozen area would rise 30 inches x 0.10 or 3 inches above an unfrozen area.

The tanks of this dike system all set directly upon an 8 inch thick reinforced concrete slab-on grade, 30'-0" wide x 111'-3"long.

Assuming the maximum condition where the narrow side of the slab-on-grade has 30 inches of water under it, and the other side has 30 inches of ice, the differential due to frost heave would be 3 inches vertical movement in 30'-0" horizontal distance.

A. Proportion to find differential elevation of base:

$$\frac{V}{H} = \frac{Y}{h}$$

V = Vertical movement of slab (inches)
H = Horizontal length of slab (ft.)
Y = Vertical rise of tank edge (inches)
h = Horizontal distance between tank edges,
diameter of tank (ft.)

Y = (V/H) x (h)
= (3" / 30'-0") x (12'-0") = 1.2000 inch vert. rise

B. Proportion to find resulting offset of Center of Gravity of tank:

$$\frac{Y}{h} = \frac{X}{d}$$

X = Horizontal offset distance to center of tank (inches)
d = Vertical distance from base to center of tank (ft.)

X = (Y/h) x (d)
= (1.200" / 12'-0") x (25'-0") /2 = 1.2500 in. = 0.1042 ft.

C. Calculate resulting Frost Resisting Moment:
FRM = DL x delta

FRM = Frost Resisting Moment (ft. kips)
DL = Dead Load of Tank (Weight of empty tank) (lbs)
delta = Horizontal Distance from center of tank to its overturning point (ft.)

FRM = 9,993 lbs/1000 lbs/kip x [(12'-0") /2 - 0.1042] = 58.92 ft. kips

D. Overturning Moment due to Wind Force: [para. 7.C.]
OTM = 39.0 ft. kips

E. Factor of Safety Against Overturning:
Factor of Safety (FOS) = FRM/OTM = 58.9/39.0 = 1.51 > 1.5
OK

## 9. Foundation Investigation [14.1]

The bottom of the containment area is a reinforced concrete slab, 8 inch minimum thickness.

| | |
|---|---|
| Total weight of a fully loaded tank produces a base pressure of | 2,163 psf |
| The 6" house keeping pad produces a pressure of (6"/12" × 150 lbs/cu. ft.) | 75 psf |
| The 8" base slab produces a pressure of (8"/12" × 150 lbs/cu. ft.) | 100 psf |
| Total soil pressure under each tank | 2,338 psf |
| Existing soil bearing | [21] |
| Allowable soil bearing capacity | 4,000 psf |

The concrete base slab and the soil capacity is adequate to carry the tanks

## 10. Containment Wall Investigation

A. Construction [14.1]

Reinforced concrete wall, doweled to the base slab
12" wide by 3'-0" high
Vertical reinforcing consists of #4 bars at 18" on centers, both faces
Horizontal reinforcing consists of #4 bars at 14" on centers, both faces

B. Wall Design [18]

$P = 1/2\ w\ h^2$

P = Force on wall due to the contained liquid pressure (lbs per ft. of length)
w = Weight of contained liquid (lbs / cubic ft.)
h = Height of contained liquid (ft.)

$P = 1/2\ (62.4 \times 1.33) \times (3'\text{-}0'')^2 = 373.5$ lbs / ft.

$M = 1/3\ P\ h$

M = Moment at base of wall (ft. lbs / ft.)
P = Force on wall (lbs / ft.)
h = Height of contained liquid (ft.)

$M = 1/3 \times 373.5 \times 3'\text{-}0'' = 373.5$ ft. lbs / ft or 0.374 ft. kips / ft.

$RM = A_s\ a\ d$ [Simplified concrete beam design function -- ]
[American Concrete Institute publication -- ACI SP-3]

RM = Resisting Moment at base of wall (ft. lbs / ft.)
$A_s$ = Area of reinforcing steel (sq. inches / ft.) -- (for #4 @ 18", $A_s = 0.13$) [15]
a = Coefficient of concrete design (for 24 ksi steel and 3 ksi concrete use 1.76) [16]
d = Distance from face of wall to centerline of far reinforcing bar.

$RM = 0.13 \times 1.76 \times (12''\text{-}2'') = 2.29$ ft. kips / ft.

C. Factor of Safety of Containment Wall

Factor of Safety (FOS) = RM / M = 2.29 / 0.374 = 6.1

Since FOS is greater than 1.0, wall will safely contain the full height of 1.33 s.g. fluid.

# Structural Assessment of a Hazardous Waste Storage Tank for Hukill Chemical Company

*by S. M. Haw Associates, Inc.*

*Professional Engineers*

November 10, 1995

## 1. Description [A]

*Hazardous Waste Dike Identification*: .....7 Tank Dike System
*Tank Designation*: ..................................V-4000C
*Rated Capacity*: .......................................4,000 Gallons
*Specific Gravity of Contained Liquid*: .....1.33 (maximum use)
*Part B Application, Section D Location*: .Exhibit D-2
*Tank Construction*: .Vertical, welded carbon steel plate with cone bottom and 4 legs [1.3]
*Design Standard:* ............None
*Material Specifications*: ...Shell, Assumed Minimum ASME SA 515 Grade 55 carbon steel [2.1]
Legs, Steel Beams ASTM A36
*Tank Dimensions*: ............Cyl. Shell Height: 6'-1" Shell Diameter: 10'-0" [1.3]
Bottom Cone Height: 2'-10" Shell Thickness (Assumed): 1/4"
Total Height: 12'-0" Cone Thickness (Assumed): 5/16"
*Tank Shell Thickness Measurements:* Minimum measured shell, top: 0.223 inches [3.7]
Minimum measured shell, cone: 0.282 inches

## 2. Weight of Tank

Cylindrical Shell Area: $A = \pi \times d \times h$ [4]
$= 3.1416 \times 10.0 \times 6.08 = 191.0$ sq. ft
Cylindrical Shell Weight: $Wt = A \times$ (pl. wt.) [8.1]
$= 191.0 \times 10.2$ lbs./sq. ft. (1/4") = 1,948 lb

Top Area: $A = \pi \times d^2/4$ [5]
$= 3.1416 \times 10.0 \times 10.0 / 4 = 78.5$ sq. ft.
Top Weight: $Wt = A \times$ (pl. wt.) [8.1]
$= 78.5 \times 10.2$ lbs./sq. ft.(1/4") = 801 lb

Bottom Cone Slant Hgt.: $c = \sqrt{a^2 + b^2}$ [6]
$= \sqrt{(2.82)^2 + (5.00)^2} = 5.74$
Bottom Cone Area: $A = 1/2 \times \pi \times d \times s$ [7]
$= 1/2 \times \pi \times 10.0 \times 5.74 = 90.2$ sq. ft.
Bottom Cone Weight: $Wt = A \times$ (pl. wt.) [8.1]
$= 90.2 \times 12.8$ lbs./sq. ft. (5/16") = 1,155 lb

Legs, Weight: 4 Beams - W6 x 16 (16 plf) × 8'-8" = 34'-0 ft. × 16 = 555 lb

Structural Assessment of a Hazardous Waste Storage Tank
for Hukill Chemical Company
7 Tank Dike System -- Tank V-4000C

| | | |
|---|---|---|
| Bot. Angle, Weight: | 1 Angle $4 \times 4 \times 1/4$ (6.6 plf)<br>$4 \times 7.17$ ft. $\times 6.6$ plf = | [17-pg 1-48]<br>189 lb |
| Weight of Agitator: | | 300 lb |
| Weight of Miscellaneous Appurtenances: | | 500 lb |
| TOTAL WEIGHT OF TANK: | | 5,448 lb |

**3. Weight of Contained Liquid**

Volume of tank above cone: $V = \pi \times d^2/4 \times ht$ [4]

$= \pi \times 10.0^2 /4 \times 6.08 = 478$ cu. ft.

Weight of liquid above cone: Wgt = Vol × 62.4 × sp. gr.

$= 478 \times 62.4 \times 1.33 =$ 39,670 lb

Volume of cone: $V = 1/3 \times \pi \times d^2/4 \times ht$ [7]

$= 1/3 \times \pi \times 10.0^2 /4 \times 2.83 = 74$ cu. ft.

Weight of liquid in cone: Wgt = Vol × 62.4 × sp. gr.

$= 74 \times 62.4 \times 1.33 =$ 6,141 lb

Total Liquid Weight: 45,811 lb

**4. Check Tank Legs**

Tank Legs: Beam - W6 x 16 -- Length = 2'-10" + 3'-1" = 5'-11"

Area = 4.74 sq. in. -- Radius of gyration (y axis) = 0.966 in. [17-pg 1-32 & 33]

Total Weight of Tank & Liquid: 5,448 lb. + 45,811 lb. = 51,259 lb

Load on one leg: 51,259 lb. / 4 = 12,815 lb

Slenderness ratio: $K \times l / r_y = 1.0\ (5.92 \times 12)/0.966 = 74$

Allowable Comp. Stress: $F_a$ (find from AISC Table 3-36) = 16.01 ksi [17-pg 5-42 & 5-135]

Actual Compressive Stress: $f_a = P/A = (12{,}815 / 1000) / 4.74 = 2.70$ ksi $< 16.01$

Conclusion: Legs are OK

**5A. Calculation of Required Tank Wall Thickness -- Cylindrical Shell**

$$t_h = \frac{2.60 \times h \times d \times g}{f \times E}$$ [11-Eq. 4]

$t_h$ = Minimum required shell plate thickness (inches)
h = Depth from top of tank (feet)
d = Diameter of tank (ft.)
g = Specific gravity of contained liquid
f = Allowable unit stress (13,700 psi) [2.1]
E = Joint efficiency factor (0.66) [11-Table 1]

$$t_h = \frac{2.60 \times 6.08 \times 10.0 \times 1.33}{13{,}700 \times 0.66} = 0.0233 \text{ inches}$$

Minimum measured thickness = 0.223 inches

Service Factor (SF) = $\dfrac{t_{actual}}{t_{required}} = \dfrac{0.223}{0.0233} = 9.57$

Conclusion: The cylindrical shell is OK

**5B. Calculation of Required Tank Wall Thickness -- Cone**

Longitudinal Force at Spring Line

$$T_2 = \frac{\gamma}{2Cos\theta} \times \frac{D}{2} \times (X + \frac{D}{6} \times Cot\theta)$$ [11-Eq. 32]

$T_2$ = Total Force (lb/ft.)
$\gamma$ = Density of liquid (pcf)
D = Tank Diameter (feet)
X = Distance from top of tank (feet)
hc = Height of cone
$\theta$ = Apex angle (degrees) $= \tan^{-1}\dfrac{D/2}{h_c} = \tan^{-1}\dfrac{5.00}{2.83} \therefore \theta = 60°$ [6]

$$T_2 = \frac{(62.4 \times 1.33)}{2Cos60°} \times \frac{10.0}{2} \times (6.08 + \frac{10.0}{6} \times Cot60°) = 2{,}923 \text{ lb/ft.}$$

Hoop Force at Spring Line (Intersection of Shell and Cone)

$$T_1 = \frac{\gamma \times D \times X}{2\ \mathrm{Cos}\theta}$$ [11-Eq. 33]

$T_1$ = Total Force (lbs/ft.)
$\gamma$ = Desity of contained liquid (lbs/cu.ft.)
D = Tank diameter (feet)
X = Distance from top of tank (feet)
$\theta$ = Apex angle (degrees)

$$T_1 = \frac{(62.4 \times 1.33) \times 10.0 \times 6.08}{2\mathrm{Cos}60^\circ} = 5{,}046 \text{ lb/ft.} > 2{,}923 \text{ lb./ft.}$$

$$t_h = \frac{T_T}{f \times E} = \frac{5{,}046/12}{13700 \times 0.66} = 0.0465 \text{ inches}$$ [11-Eq. 4]

$t_h$ = Minimum required cone shell plate thickness (inches)
$T_T$ = Total force on one foot strip (lb./in.)
f = Allowable steel unit stress (13,700 psi) [2.1]
E = Joint efficiency factor (0.66) [11-Table 1]

The measured minimum plate thickness in the cone is 0.282"

Service factor (SF) $\frac{t_{\mathrm{actual}}}{t_{\mathrm{required}}} = \frac{0.282}{0.0465} = 6.06$ Therefore, cone shell is OK

## 5C. Calculation at Cone to Cylinder Junction

$$C = \frac{\gamma}{8}(X + \frac{D}{6}Cot\theta)D^2 Tan\theta$$ [11-Eq. 34]

C = Compressive force (lbs)
$\gamma$ = Density of contained liquid (pcf)
X = Distance from top of tank (ft.)
D = Diameter of tank (ft.)
$\theta$ = Apex angle of cone (degrees)

$$C = \frac{62.4 \times 1.33}{8}(6.08 + \frac{10.0}{6} Cot 60°) 10.0^2 Tan 60° = 12{,}654 \text{ lb}$$

$$A_{eff} = 0.78(t_c\sqrt{(R_c t_c)} + t_1\sqrt{(R_1 t_1)}) \qquad [11\text{-Eq. } 35a]$$

$A_{eff}$ = Effective area of compression (sq. in.)
$t_c$ = Thickness of cone (inches)
$R_c$ = Radius of cone base (inches)
$t_1$ = Thickness of cylindrical shell (inches)
$R_1$ = Radius of shell (inches)

$$A_{eff} = 0.78[0.282\sqrt{(60 \times 0.282)} + 0.223\sqrt{(60 \times 0.223)}] = 1.54 \text{ sq. in.}$$

$$A_{eff_{max}} = 16(t_c^2 + t_1^2) = 16(0.282^2 + 0.223^2) = 2.07 \text{ sq. in. --- Use } 1.54 \text{ sq. in.} \qquad [11\text{-Eq. } 35b]$$

Summation of Forces at Cone to Cylinder Junction

Compression force = 12,654 lb
Combined tension force = 6,115 lb
Net Compressive force = 6,539 lb

$$\text{Compressive stress} = \frac{NCF}{A_{eff}} = \frac{6539}{1.54} = 4{,}246 \text{ psi}$$

Maximum allowable compressive stress

$$f_a = 2{,}000{,}000\frac{t}{R}(1 - \frac{100}{3}\frac{t}{R}) \qquad [11\text{-Eq. } 26]$$

$f_a$ = Allowable compressive unit stress (psi)
t = Plate thickness (in.)
R = Radius of curvature normal to direction of stress (in.)

$$f_a = 2{,}000{,}000\frac{0.223}{60}(1 - \frac{100}{3} \times \frac{0.223}{60}) = 6{,}512 \text{ psi} < 15{,}000 \text{ psi}$$

$$\text{Service Factor (SF)} = \frac{f_{allow}}{f_{actual}} = \frac{6512}{4246} = 1.53 \quad \text{Cone to cylinder junction O.K.}$$

**6. Calculation of Seismic Forces on the Tank**

A. Seismic Formula -- Seismic Zone #1 (Ohio) [Ohio Basic Building Code = OBBC]

$V = 2.5\ A_v\ I\ K\ C\ S\ W$ [OBBC 1113.4]

V = Lateral Seismic Force (lbs)
$A_v$ = 0.075 (Coefficient for Ohio) [OBBC 1113.4.1]
I = Importance Factor (For industrial plants, I = 1.0) [OBBC 1113.4.2]
K = Horizontal Force Factor (For a tank on legs, K = 2.5) [OBBC 1113.4.3] [& OBBC 1113.9.3]
C S = Coefficient combination (For zones 0, 1 & 2, CS = 0.14) [OBBC 1113.4.4]
W = Weight of the fully loaded tank (lbs)

$V = 2.5 \times 0.075 \times 1.0 \times 2.5 \times 0.14 \times (5{,}448 \text{ lbs} + 45{,}811 \text{ lbs}) = 3{,}366 \text{ lbs}$

B. Overturning Moment Due to Seismic Force

$OTM = V / 1000 \times arm$

OTM = Overturning Moment about base (ft. kips)
arm = Vertical Distance from the base to center of gravity of loaded tank(ft.)
arm = (6'-1") /2 + 2'-10" + 3'-1" = 8.96'

OTM = 3,366 lbs/1000 lbs/kip × 8.96' = 30.2 ft. kips

C. Resisting Moment of the Tank -- Full Tank

$RM = W / 1000 \times delta$

RM = Resisting Moment (ft. kips)
delta = Horizontal Distance from the center of the tank to its overturning point (ft.)

RM = (5,448 lbs + 45,811 lbs) /1000 lbs /kip × (7'-2") /2 = 183.7 ft. kips

D. Factor of Safety Against Seismic Overturning

Factor of Safety (FOS) = RM / OTM = 183.7 / 30.2 = 6.1

Since FOS is greater than 1.5, tank is safe against overturning from seismic forces.

**7. Calculation of Wind Forces on the Tank** [Ohio Basic Building Code = OBBC]

A. Wind Formula -- 80 mph wind zone -- Exposure B

$P_d = P_e \times I^2 \times C_p$ [OBBC 1112.3]

Definitions as follows: [OBBC 1112.2]

$P_d$ = Design Wind Pressure (lbs per sq. ft.)

$P_e$ = Effective Velocity Pressure - Exposure B ($P_e$ = 13psf) [OBBC Table 1112.3.3a ]

I = Importance Factor for Service (I = 1.0) [OBBC Table 1112.2a(1)]

$C_p$ = External Pressure Coefficient for Round Tanks [OBBC Table 1112.2d ]

For h/D = 12'-0" / 10'-0" = 1.20, $C_p$ = 0.8

$P_d = 13 \times (1.0)^2 \times 0.8 = 10.4$ psf

B. Wind Force on Tank

$P_1 = P_d \times$ Wind Area - Cylinder

Wind Area = D × h = 10'-0" × 6'-1" = 60.8 sq. ft.

D = Tank Diameter (ft.)

h = Tank Height (ft.)

$P_1 = 10.4 \times 60.8 = 632$ lbs.

$P_2 = P_d \times$ Wind Area - Cone

Wind Area = $\dfrac{D+d}{2} \times h$ = (10'-0" + 0") /2 × 2'-10" = 14.2 sq. ft.

d = Bottom cone diameter

h = Cone height

$P_2 = 10.4 \times 14.2 = 148$ lb.

C. Overturning Moment due to Wind Force

OTM = P /1000 × arm

arm = Vertical Distance from the base to center of gravity of the wind area (ft.)

$arm_1$ = (6'-1") /2 + 2'-10" + 3'-1" = 8.96 ft.

$arm_2$ = (2'-10") × 2/3 + 3'-1" = 4.97 ft.

OTM = 632 lbs /1000 lbs/kip × 8.96' + 148 lb./1000 lb./kip × 4.97'= 6.4 ft. kips

D. Resisting Moment of Tank -- Empty Tank

RM = DL / 1000 × delta

RM = Resisting Moment (ft. kips)

DL = Dead Load of Tank (Weight of empty tank) (lbs)

delta = Horizontal Distance from center of tank to its overturning point (c/c legs /2)

RM = 5,448 lbs /1000 lbs/kip × (7'-2") /2 = 19.5 ft. kips

E. Factor of Safety Against Wind Overturning
Factor of Safety (FOS) = RM / OTM = 19.5 / 6.4 = 3.0
Since FOS is greater than 1.5, tank is safe against overturning from wind forces.

**8. Frost Heave** [14.1]

Maximum frost design depth per local Building Code in this area is 30 inches.

Assuming the underlaying soil is completely saturated with water and had frozen solid and using an expansion factor of water to ice as 10%, the frozen area would rise 30 inches x 0.10 or 3 inches above an unfrozen area.

The tanks of this dike system all set directly upon an 8 inch thick reinforced concrete slab-on grade, 30'-0" wide x 111'-3"long.

Assuming the maximum condition where the narrow side of the slab-on-grade has 30 inches of water under it, and the other side has 30 inches of ice, the differential due to frost heave would be 3 inches vertical movement in 30'-0" horizontal distance.

A. Proportion to find differential elevation of base:

$$\frac{V}{H} = \frac{Y}{h}$$

V = Vertical movement of slab (inches)
H = Horizontal length of slab (ft.)
Y = Vertical rise of tank edge (inches)
h = Horizontal distance between tank legs (ft.)

Y = (V/H) x (h)
= (3" / 30'-0") x (7'-2") = 0.7167 inch vert. rise

B. Proportion to find resulting offset of Center of Gravity of tank:

$$\frac{Y}{h} = \frac{X}{d}$$

H = Horizontal offset distance to center of tank (inches)
d = Vertical distance from base to center of tank (ft.)
= (6'-1") /2 + 2'-10" + 3'-1" = 8'-11"

X = (Y/h) x (d )
= 0.7167" / 7'-2") x (8'-11) /2 = 0.8959 in. = 0.0747 ft.

C. Calculate resulting Frost Resisting Moment:
FRM = DL x delta

FRM = Frost Resisting Moment (ft. kips)
DL = Dead Load of Tank (Weight of empty tank) (lbs)
delta = Horizontal Distance from center of tank to its overturning point (ft.)

FRM = 5,448 lbs/1000 lbs/kip x [(7'-2") /2 - 0.0747] = 19.12 ft. kips

D. Overturning Moment due to Wind Force: [para. 7.C.]
OTM = 6.4 ft. kips

E. Factor of Safety Against Overturning:
Factor of Safety (FOS) = FRM/OTM = 19.12/6.4 = 2.98 > 1.5
OK

**9. Foundation Investigation** [14.1]

The bottom of the containment area is a reinforced concrete slab, 8 inch minimum thickness.
Tank has 4 legs, each with a loading of 12,815 lbs. and each with a 12" sq. base plate.
Area of soil bearing under a leg is $(8" + 12" + 8")^2 = (2'\text{-}4")^2 = 5.44$ sq. ft.

| | |
|---|---|
| Each leg produces a base pressure of 12,815 / 5.44 sq. ft. = | 2,356 psf |
| The 8" base slab produces a pressure of (8"/12" × 150 lbs/cu. ft.) | 100 psf |
| Total soil pressure under each tank leg | 2,456 psf |

Existing soil bearing [21]
Allowable soil bearing capacity is 4,000 psf
The concrete base slab and the soil capacity is adequate to carry the tanks

**10. Containment Wall Investigation**

A. Construction [14.1]
Reinforced concrete wall, doweled to the base slab
12" wide by 3'-0" high
Vertical reinforcing consists of #4 bars at 18" on centers, both faces
Horizontal reinforcing consists of #4 bars at 14" on centers, both faces

B. Wall Design [18]

$P = 1/2\ w\ h^2$

P = Force on wall due to the contined liquid pressure (lbs per ft. of length)
w = Weight of contained liquid (lbs / cubic ft.)
h = Height of contained liquid (ft.)

$P = 1/2\ (62.4 \times 1.33) \times (3'\text{-}0")^2 = 373.5$ lbs / ft.

$M = 1/3\ P\ h$

M = Moment at base of wall (ft. lbs / ft.)
P = Force on wall (lbs / ft.)
h = Height of contained liquid (ft.)

$M = 1/3 \times 373.5 \times 3'\text{-}0" = 373.5$ ft. lbs / ft or 0.374 ft. kips / ft.

$RM = A_s\ a\ d$ [Simplified concrete beam design function -- ]
[American Concrete Institute publication -- ACI SP-3

RM = Resisting Moment at base of wall (ft. lbs / ft.)
$A_s$ = Area of reinforcing steel (sq. inches / ft.) -- (for #4 @ 18", $A_s = 0.13$) [15]
a = Coefficient of concrete design (for 24 ksi steel and 3 ksi concrete use 1.76) [16]
d = Distance from face of wall to centerline of far reinforcing bar.

$RM = 0.13 \times 1.76 \times 12"\text{-}2") = 2.29$ ft. kips / ft.

C. Factor of Safety of Containment Wall

Factor of Safety (FOS) = RM / M = 2.29 / 0.374 = 6.1

Since FOS is greater than 1.0, wall will safely contain the full height of 1.33 s.g. fluid.

# Structural Assessment of a Hazardous Waste Storage Tank for Hukill Chemical Company

*by S. M. Haw Associates, Inc.*

*Professional Engineers*

November 10, 1995

## 1. Description [A]

*Hazardous Waste Dike Identification:*.....7 Tank Dike System
*Tank Designation:*..................................V-1500C
*Rated Capacity:*.......................................1,500 Gallons
*Specific Gravity of Contained Liquid:* .....1.33 (Maximum Use)
*Part B Application, Section D Location:* .Exhibit D-2
*Tank Construction:* .Vertical, welded carbon steel plate with cone bottom and 4 legs [1.3]
*Design Standard:* ............None
*Material Specifications:*...Shell, Assumed Minimum ASME SA 515 Grade 55 carbon steel[2.1]
Legs, Steel Angles ASTM A36

*Tank Dimensions:*.............

| | | |
|---|---|---|
| Cyl. Shell Height: 8'-11" | Shell Diameter: 5'-0" | [1.3] |
| Bottom Cone Height: 2'-6" | Shell Thickness (Assumed): 3/16" | |
| Total Height: 15'-0" | Cone Thickness (Assumed): 1/8" | |

*Tank Shell Thickness Measurements:*

| | | |
|---|---|---|
| Minimum measured shell, top: | 0.160 inches | [3.6] |
| Minimum measured shell, bottom: | 0.142 inches | |
| Minimum measured shell, cone: | 0.117 inches | |

## 2. Weight of Tank

Cylindrical Shell Area: $A = \pi \times d \times h$ [4]

$= 3.1416 \times 5.0 \times 8.92 = 140.1$ sq. ft

Cylindrical Shell Weight: $Wt = A \times$ (pl. wt.) [8.1]

$= 140.1 \times 7.66$ lbs./sq. ft. (3/16") = 1,073 lb

Top Area: $A = \pi \times d^2/4$ [5]

$= 3.1416 \times 5.0 \times 5.0 / 4 = 19.6$ sq. ft.

Top Weight: $Wt = A \times$ (pl. wt.) [8.1]

$= 19.6 \times 7.66$ lbs./sq. ft. (3/16") = 150 lb

Bottom Cone Slant Hgt.: $c = \sqrt{a^2 + b^2}$ [6]

$= \sqrt{(2.50)^2 + (2.50)^2} = 3.54$ ft.

Bottom Cone Area: $A = 1/2 \times \pi \times d \times s$ [7]

$= 1/2 \times \pi \times 5.0 \times 3.54 = 27.8$ sq. ft.

Bottom Cone Weight: $Wt = A \times$ (pl. wt.) [8.1]

$= 27.8 \times 5.1$ lbs./sq. ft. (1/8") = 142 lb

Legs, Weight: 4 Angles - 3" x 3" x 1/4" (4.9 plf) [17- pg 1-49]

$4 \times$ 7'-8" = 30.7 ft. $\times$ 4.9 = 150 lb

| | | |
|---|---|---|
| Diag. Angles, Weight: | 2 Angles 2" × 2" × 1/4" (3.19 plf) | [17 - pg 1-50] |
| | 4 × 2 × 6'-6" ft. × 3.19 plf = | 168 lb |
| Weight of Miscellaneous Appurtenances: | | 500 lb |
| TOTAL WEIGHT OF TANK: | | 2,183 lb |

## 3. Weight of Contained Liquid

Volume of tank above cone: $V = \pi \times d^2/4 \times ht$ [4]

$= \pi \times 5.0^2/4 \times 8.92 = 175$ cu. ft.

Weight of liquid above cone: Wgt = Vol × 62.4 × sp. gr.

= 175 × 62.4 × 1.33 = 14,536 lb

Volume of cone: $V = 1/3 \times \pi \times d^2/4 \times ht$ [7]

$= 1/3 \times \pi \times 5.0^2/4 \times 2.50 = 16$ cu. ft.

Weight of liquid in cone: Wgt = Vol × 62.4 × sp. gr.

= 16 × 62.4 × 1.33 = 1,328 lb

Total Liquid Weight: 15,864 lb

## 4. Check Tank Legs

Tank Legs: 1 Angle - 3" x 3" x 1/4" -- Length = 2'-6" + 3'-7" = 6'-1"
Area = 1.44 sq. in. -- Radius of gyration (z axis) = 0.592 in. [17 - pg. 1-49]

Total Weight of Tank & Liquid: 2,183 lb. + 15, 864 lb. = 18,047 lb

Load on one leg: 18,047 lb. / 4 legs 4,512 lb

Slenderness ratio: $K \times l/r_z$ = 1.0 (6.08 × 12)/0.592 = 123 [17 - pg. 5-42 & 5-135]

Allowable Comp. Stress: $F_a$ (find from AISC Table 6-36) = 9.85 ksi [17 - pg. 3-16]

Actual Compressive Stress: $f_a = P/A = (4{,}512 / 1000) / 1.44 = 3.13 \text{ ksi} < 9.85 \text{ ksi}$

Conclusion: Legs are OK

**5A. Calculation of Required Tank Wall Thickness -- Cylindrical Shell**

$$t_h = \frac{2.60 \times h \times d \times g}{f \times E}$$ [11-Eq. 4]

$t_h$ = Minimum required shell plate thickness (inches)
h = Depth from top of tank (feet)
d = Diameter of tank (ft.)
g = Specific gravity of contained liquid
f = Allowable unit stress (13,700 psi) [2.1]
E = Joint efficiency factor (0.66) [11-Table 1]

$$t_h = \frac{2.60 \times 8.92 \times 5.0 \times 1.33}{13{,}700 \times 0.66} = 0.0171 \text{ inches}$$

Minimum measured thickness = 0.142 inches

Service Factor (SF) = $\frac{t_{actual}}{t_{required}} = \frac{0.142}{0.0171} = 8.33$

Conclusion: The cylindrical shell is OK

**5B. Calculation of Required Tank Wall Thickness -- Cone**

Longitudinal Force at Spring Line

$$T_2 = \frac{\gamma}{2Cos\theta} \times \frac{D}{2} \times (X + \frac{D}{6} \times Cot\theta)$$ [11-Eq. 32]

$T_2$ = Total Force (lb/ft.)
$\gamma$ = Density of liquid (pcf)
D = Tank Diameter (feet)
X = Distance from top of tank (feet)
hc = Height of cone
$\theta$ = Apex angle (degrees) $= \tan^{-1}\frac{D/2}{h_c} = \tan^{-1}\frac{2.50}{2.50} \therefore \theta = 45°$ [6]

$$T_2 = \frac{(62.4 \times 1.33)}{2Cos45°} \times \frac{5.0}{2} \times (8.92 + \frac{5.0}{6} \times Cot45°) = 1{,}431 \text{ lb/ft.}$$

Hoop Force at Spring Line (Intersection of Shell and Cone)

$$T_1 = \frac{\gamma \times D \times X}{2\ \mathrm{Cos}\theta}$$ [11-Eq. 33]

$T_1$ = Total Force (lbs/ft.)
$\gamma$ = Desity of contained liquid (lbs/cu.ft.)
D = Tank diameter (feet)
X = Distance from top of tank (feet)
$\theta$ = Apex angle (degrees)

$$T_1 = \frac{(62.4 \times 1.33) \times 5.0 \times 8.92}{2\mathrm{Cos}45°} = 2{,}617 \text{ lb/ft.} > 1{,}431 \text{ lb./ft.}$$

$$t_h = \frac{T_T}{f \times E} = \frac{2617/12}{13700 \times 0.66} = 0.024 \text{ inches}$$ [11-Eq. 4]

$t_h$ = Minimum required cone shell plate thickness (inches)
$T_T$ = Total force on one foot strip (lb/ft.)
f = Allowable steel unit stress (13,700 psi) [2.1]
E = Joint efficiency factor (0.66) [11-Table 1]

The measured minimum plate thickness in the cone is 0.117"

Service factor (SF) is $\frac{t_{actual}}{t_{required}} = \frac{0.117}{0.024} = 4.85$ Therefore, cone shell is OK

**5C. Calculation at Cone to Cylinder Junction**

$$C = \frac{\gamma}{8}(X + \frac{D}{6}Cot\theta)D^2 Tan\theta$$ [11-Eq. 34]

C = Compressive force (lbs)
$\gamma$ = Density of contained liquid (pcf)
X = Distance from top of tank (ft.)
D = Diameter of tank (ft.)
$\theta$ = Apex angle of cone (degrees)

$$C = \frac{62.4 \times 1.33}{8}(8.92 + \frac{5.0}{6}Cot45°)5.0^2 Tan45° = 2{,}530 \text{ lb}$$

$$A_{eff} = 0.78(t_c\sqrt{(R_c t_c)} + t_1\sqrt{(R_1 t_1)}$$ [11-Eq. 35a]

$A_{eff}$ = Effective area of compression (sq. in.)
$t_c$ = Thickness of cone (inches)
$R_c$ = Radius of cone base (inches)
$t_1$ = Thickness of cylindrical shell (inches)
$R_1$ = Radius of shell (inches)

$$A_{eff} = 0.78[0.117\sqrt{(30 \times 0.117)} + 0.142\sqrt{(30 \times 0.142)}] = 0.400 \text{ sq. in.}$$

$$A_{eff_{max}} = 16(t_c^2 + t_1^2) = 16(0.117^2 + 0.142^2) = 0.542 \text{ sq. in.}$$ --- Use 0.400 sq. in. [11-Eq. 35b]

Summation of Forces at Cone to Cylinder Junction

Compression force = 2,530 lb
Combined tension force = 3,056 lb
Net Compressive force = 526 lb

$$\text{Compressive stress} = \frac{N}{A_{eff}} = \frac{526}{0.400} = 1{,}315 \text{ psi}$$

Maximum allowable compressive stress

$$f_a = 2{,}000{,}000\frac{t}{R}(1-\frac{100}{3}\frac{t}{R}) \qquad \text{[11-Eq. 26]}$$

$f_a$ = Allowable compressive unit stress (psi)
t = Plate thickness (in.)
R = Radius of curvature normal to direction of stress (in.)

$$f_a = 2{,}000{,}000\frac{0.117}{30}(1-\frac{100}{3}\times\frac{0.117}{30}) = 6{,}786 \text{ psi} < 15{,}000 \text{ psi (max)}$$

Service Factor (SF) = $\frac{f_{allow}}{f_{actual}} = \frac{6786}{1315} = 5.2$ Cone to cylinder junction O.K.

**6. Calculation of Seismic Forces on the Tank**

A. Seismic Formula -- Seismic Zone #1 (Ohio) [Ohio Basic Building Code - OBBC]

$V = 2.5\ A_v\ I\ K\ C\ S\ W$ [OBBC 1113.4]

V = Lateral Seismic Force (lbs)
$A_v$ = 0.075 (Coefficient for Ohio) [OBBC 1113.4.1]
I = Importance Factor (For industrial plants, I = 1.0) [OBBC 1113.4.2]
K = Horizontal Force Factor (For a tank on legs, K = 2.5) [OBBC 1113.4.3] [& OBBC 1113.9.3]
C S = Coefficient combination (For zones 0, 1 & 2, CS = 0.14) [OBBC 1113.4.4]
W = Weight of the fully loaded tank (lbs)

$V = 2.5 \times 0.075 \times 1.0 \times 2.5 \times 0.14 \times (2{,}183 \text{ lbs} + 15{,}864 \text{ lbs}) = 1{,}184 \text{ lbs}$

B. Overturning Moment Due to Seismic Force

OTM = V /1000 × arm

OTM = Overturning Moment about base (ft. kips)
arm = Vertical Distance from the base to center of gravity of loaded tank(ft.)
arm = (8'-11")/2 + 2'-6" + 3'-7" = 10.54

OTM = 1,184 lbs/1000 lbs/kip × (10.54) = 12.5 ft. kips

C. Resisting Moment of the Tank -- Full Tank

RM = W /1000 × delta

RM = Resisting Moment (ft. kips)

delta = Horizontal Distance from the center of the tank to its overturning point (ft.)

RM = (2,183 lbs+ 15,864 lbs) /1000 lbs /kip × (3'-9 3/4") /2 = 34.4 ft. kips

D. Factor of Safety Against Seismic Overturning

Factor of Safety (FOS) = RM / OTM = 34.4 / 12.5 = 2.7

Since FOS is greater than 1.5, tank is safe against overturning from seismic forces.

**7. Calculation of Wind Forces on the Tank** [Ohio Basic Building Code - OBBC]

A. Wind Formula -- 80 mph wind zone -- Exposure B

$P_d = P_e \times I^2 \times C_p$ [OBBC 1112.3]

Definitions as follows: [OBBC 1112.2]

$P_d$ = Design Wind Pressure (lbs per sq. ft.)

$P_e$ = Effective Velocity Pressure - Exposure B ($P_e$ = 13psf) [OBBC Table 1112.3.3a ]

I = Importance Factor for Service (I = 1.0) [OBBC Table 1112.2a(1)]

$C_p$ = External Pressure Coefficient for Round Tanks [OBBC Table 1112.2d ]

For h/D = 15'-0" / 5'-0" = 3.0, $C_p$ = 0.8

$P_d = 13 \times (1.0)^2 \times 0.8 = 10.4$ psf

B. Wind Force on Tank

$P_1 = P_d \times$ Wind Area-Cylinder

Wind Area = D × h = 5'-0" × 8'-11" = 44.6 sq. ft.

D = Tank Diameter (ft.)

h = Tank Height (ft.)

$P_1 = 10.4 \times 44.6 = 464$ lbs.

$P_2 = P_d \times$ Wind Area - Cone

Wind Area = $\frac{D+d}{2} \times h$ = (5'-0" + 0") /2 × 2'-6" = 6.3 sq. ft.

$P_2 = 10.4 \times 6.3 = 66$ lb

d = Bottom Cone Diameter

h = Cone height

C. Overturning Moment due to Wind Force

OTM = P /1000 × arm

arm = Vertical Distance from the base to center of gravity of the wind area (ft.)

$arm_1$ = (8'-11")/2 + 2'-6" + 3'-7" = 10.54 ft.

$arm_2$ = (2'-6") × 2/3 + 3'-7" = 5.25 ft.

OTM = 464 lbs /1000 lbs/kip × (10.54') + 66 lbs./1000 lbs./kip × (5.25') = 5.2 ft. kips

D. Resisting Moment of Tank -- Empty Tank

RM = DL / 1000 × delta

RM = Resisting Moment (ft. kips)

DL = Dead Load of Tank (Weight of empty tank) (lbs)

delta = Horizontal Distance from center of tank to its overturning point (c/c legs /2)

RM = 2,183 lbs /1000 lbs/kip × (3'-9 3/4") /2 = 4.2 ft. kips

E. Factor of Safety Against Wind Overturning

Factor of Safety (FOS) = RM / OTM = 4.2 / 5.2 = 0.8

Since FOS is less than 1.5, tank must be braced or anchored to adequately resist wind forces.

**8. Frost Heave** [14.1]

Maximum frost design depth per local Building Code in this area is 30 inches.

Assuming the underlaying soil is completely saturated with water and had frozen solid and using an expansion factor of water to ice as 10%, the frozen area would rise 30 inches x 0.10 or 3 inches above an unfrozen area.

The tanks of this dike system all set directly upon an 8 inch thick reinforced concrete slab-on grade, 30'-0" wide x 111'-3"long.

Assuming the maximum condition where the narrow side of the slab-on-grade has 30 inches of water under it, and the other side has 30 inches of ice, the differential due to frost heave would be 3 inches vertical movement in 30'-0" horizontal distance.

A. Proportion to find differential elevation of base:

$$\frac{V}{H} = \frac{Y}{h}$$

V = Vertical movement of slab (inches)

H = Horizontal length of slab (ft.)

Y = Vertical rise of tank edge (inches)

h = Horizontal distance between tank legs (ft.)

Y = (V/H) x (h)
= (3" / 30'-0") x (3'-9 3/4") = 0.3813 inch vert. rise

B. Proportion to find resulting offset of Center of Gravity of tank:

$$\frac{Y}{h} = \frac{X}{d}$$

H = Horizontal offset distance to center of tank (inches)
d = Vertical distance from base to center of tank (ft.)
= (8'-11") /2 + 2'-6" + 3'-7" = 10'-6 1/2"
X= (Y/h) x (d)
= (0.3813" / 3'-9 3/4") x (10'-6 1/2") /2 = 1.0543 in. = 0.0879 ft.

C. Calculate resulting Frost Resisting Moment:
FRM = DL x delta

FRM = Frost Resisting Moment (ft. kips)
DL = Dead Load of Tank (Weight of empty tank) (lbs)
delta = Horizontal Distance from center of tank to its overturning point (ft.)

FRM = 2,183 lbs/1000 lbs/kip x [(3'-9 3/4")/2 - 0.0879] = 3.97 ft. kips

D. Overturning Moment due to Wind Force: [para. 7.C.]
OTM = 5.2 ft. kips

E. Factor of Safety Against Overturning:
Factor of Safety (FOS) = FRM/OTM = 3.97/5.2 = 0.76
Since FOS if less than 1.5, this tank must be braced or anchored to adequately resist wind forces.

**9. Foundation Investigation** [14.1]

The bottom of the containment area is a reinforced concrete slab, 8 inch minimum thickness.
Tank has 4 legs, each with a loading of 4,502 lbs. and each with a 6" sq. base plate.
Area of soil bearing under a leg is $(8" + 6" + 8")^2 = (1'\text{-}10")^2$ = 3.36 sq. ft.

| | |
|---|---|
| Each leg produces a base pressure of 4,512 lbs / 3.36 sq. ft. = | 1,343 psf |
| The 8" base slab produces a pressure of (8"/12" × 150 lbs/cu. ft.) | 100 psf |
| Total soil pressure under each tank leg is | 1,443 psf |

Existing soil bearing [21]
Allowable soil bearing capacity is 4,000 psf
The concrete base slab and the soil capacity is adequate to carry the tanks

## 10. Containment Wall Investigation

A. Construction [4.1]

Reinforced concrete wall, doweled to the base slab
12" wide by 3'-0" high
Vertical reinforcing consists of #4 bars at 18" on centers, both faces
Horizontal reinforcing consists of #4 bars at 14" on centers, both faces

B. Wall Design [18]

$P = 1/2\ w\, h^2$

P = Force on wall due to the contained liquid pressure (lbs per ft. of length)
w = Weight of contained liquid (lbs / cubic ft.)
h = Height of contained liquid (ft.)

$P = 1/2\ (62.4 \times 1.33) \times (3'\text{-}0")^2 = 373.5$ lbs / ft.

$M = 1/3\ P\, h$

M = Moment at base of wall (ft. lbs / ft.)
P = Force on wall (lbs / ft.)
h = Height of contained liquid (ft.)

$M = 1/3 \times 373.5 \times 3'\text{-}0" = 373.5$ ft. lbs / ft or 0.374 ft. kips / ft.

$RM = A_s\, a\, d$ [Simplified beam design function --]
[American Concrete Institute. Publication. ACI SP-3]

RM = Resisting Moment at base of wall (ft. lbs / ft.)
$A_s$ = Area of reinforcing steel (sq. inches / ft.) -- (for #4 @ 18", $A_s = 0.13$) [15]
a = Coefficient of concrete design (for 24 ksi steel and 3 ksi concrete use 1.76) [16]
d = Distance from face of wall to centerline of far reinforcing bar.

$RM = 0.13 \times 1.76 \times (12"\text{-}2") = 2.29$ ft. kips / ft.

C. Factor of Safety of Containment Wall

Factor of Safety (FOS) = RM / M = 2.29 / 0.374 = 6.1
Since FOS is greater than 1.0, wall will safely contain the full height of 1.33 s.g. fluid.

# APPENDIX B

# SECONDARY CONTAINMENT CALCULATIONS

## SECONDARY CONTAINMENT CALCULATIONS

**7-TANK DIKE** containing V-114, V-214, V-314, V-414, V-514, V-614, V-120, V-4000C and V-1500C

The largest tank in this dike has a 21,000 gallon capacity. Containment calculations will be for the 21,000 gallons and four inches of rain, the 25-year, 24-hour rainfall event for this area.

Please refer to the 8 1/2" x 11" drawing titled "7-TANK DIKE - PLAN VIEW" on the following page for dimensions used for these calculations.

Total containment area of the dike is determined by taking the area of the 88 ft. long section at 28 ft. wide, less the triangular southeast corner area, less the southwest notch area. This is a added to a triangular section at the northeast corner and a rectangular section at the northwest, just west of the triangular section.

Area of 88 ft rectangular south section: 88 ft. x 28 ft. = 2,464 sq.ft.
Area of southeast corner to be subtracted: 1/2 x 5 ft. x 5.5 ft. = 13.75 sq.ft.
Area of southwest notch to be subtracted: 2 ft. x 3 ft. = 6 sq.ft.
Area of south section less SE corner & SW notch = 2,464 sq.ft.-13.75 sq.ft.-6 sq.ft. = 2,444 sq.ft.

NE corner, north of 88 ft. section and east of a 17.7 ft rectangle: 1/2x23 ft. x 10.3 ft. = 118.45 sq.ft.
Area of 17.7 ft. NE rectangle: 17.7 ft. x 23 ft. = 407.10 sq.ft.

Sum of three dike sections = 2,444 + 118.45 + 407.10 = **2,970 sq.ft. Total Containment Area**

The rainfall containment area would also contain the area of the wall which is approximately 1 foot wide with a perimeter of (111'+18.7'+25.2'+88'+7.4'+23.5'+3') x 1' or 277 sq.ft. Then the total Rainfall area is 2,970 sq.ft + 277 sq.ft. or **3,247 sq.ft. Rainfall Area**

Subtract the volumes of all but the largest tank within the containment. The largest tank, for which the containment volume is calculated, V-120, would not displace any liquid if it ruptured, so its volume within the containment is not included. Six tanks are 10' 8" O.D., two tanks are on legs and effectively above the containment system. Total area for the six tanks is 6(pi x (5.33 ft.)$^2$ = 536 sq.ft. Tank Displacement Area. The tanks are on 6 inch high pedestals so the bottoms of the tanks are 2.5 feet below the top of the 3 foot high wall. The tank volume displacement is 2.5' x 536 sq.ft. or **1,340 cu.ft. Tank Displacement**.

The gross containment volume is 3.0 ft. wall height x 2,970 sq.ft. or **8,910 cu.ft. Gross Volume**.

Subtract the volume of all seven octagonal pedestals. Volume formula for pedestals is area, refer to Perry's "Chemical Engineers' Handbook", of an octagon with length of each side as "l" and height of six inches. The area is $A = 4.8284\ (l)^2$ , for an eight sided polygon. Then the total area for all seven pedestals is A = 2(4.8284(6.1)$^2$ + 5(4.8284(5.667)$^2$ = 2(179.7 sq.ft.) + 5(155.1 sq.ft.) = 359.4 + 775.5 = 1,135 sq.ft. pedestal area. Using an average pedestal height of six inches, the pedestal volume to be subtracted from the gross dike containment volume is 0.5 ft. x 1,135 sq. ft. = **568 cu.ft. Pedestal Volume**.

Subtract the concrete section of the dike that is six inches higher than the rest. The area of this section is the NE triangle area subtracted from a rectangular north section of 37 ft. x 28 ft. plus the 44 ft x 8 ft section along the west side. The area of the six inch higher concrete section is then A = (39 ft. x 28 ft.) - (.5 x 23 ft. x 10.3 ft.) + (44 ft. x 8 ft.) = 1,092 - 118 + 352 = 1,326 sq.ft. The volume of this raised concrete section, including 1/2 the ramp which adds 2 feet to the length of the north section, is then .5 ft. x 1,326 sq.ft. = **663 cu.ft. Volume of 6 inch Higher Section**.

Net containment volume is the Gross volume less the Tank Displacement, Pedestal and 6 inch Higher Section volumes. This is 8,910 cu.ft. - 1,340 - 568 cu.ft. - 663 cu. ft. = **6,339 cu.ft. Net Containment Volume.**

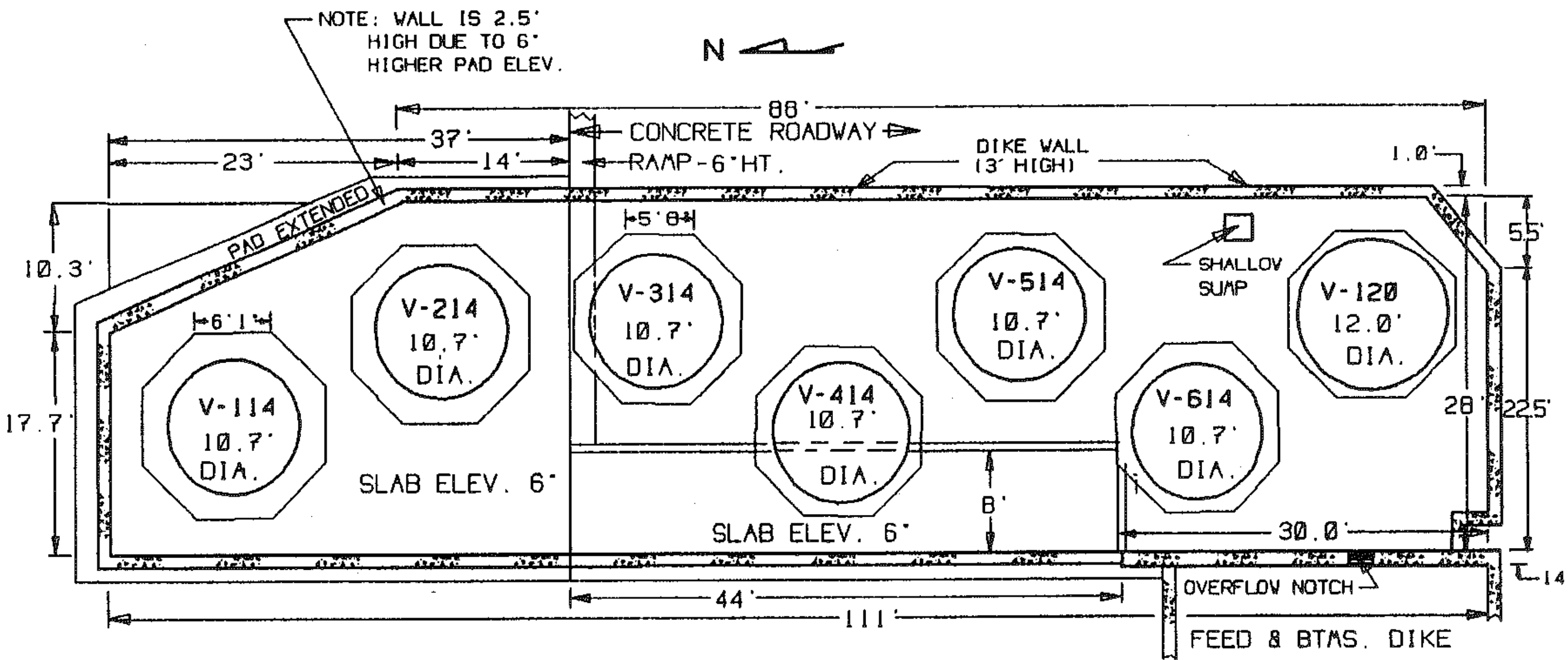
Subtract the four inch rainfall allowance of 3,247 sq.ft. Rainfall Area x .333 ft. rainfall = **1,081 cu. ft. Rainfall Volume Allowance**.

Containment remaining for largest tank spill is 6,339 Net Volume - 1,081 Rainfall = **5,258 cu.ft.**

The volume of the largest tank is 21,000 gallons or, dividing by 7.481 gal. per cu.ft., **2,807 cu.ft. for Largest Tank Spill**.

HCC has 5,258 - 2,807 = 2,451 cu.ft. OVER the required minimum containment volume for this dike system AS PER OAC 3745-55-293(E)(1)(b).

The added containment volume due to the slope of the dike and the volume of the sump were not calculated. The volume displaced by the steel supports for the two small cone bottom tanks, V-4000C and V-115C was not calculated.




## 7-TANK DIKE - PLAN VIEW

(DIKE SLAB SLOPES TO SUMP)

NOTE: Please Use With Containment Calculations.

**HUKILL CHEMICAL CORPORATION**

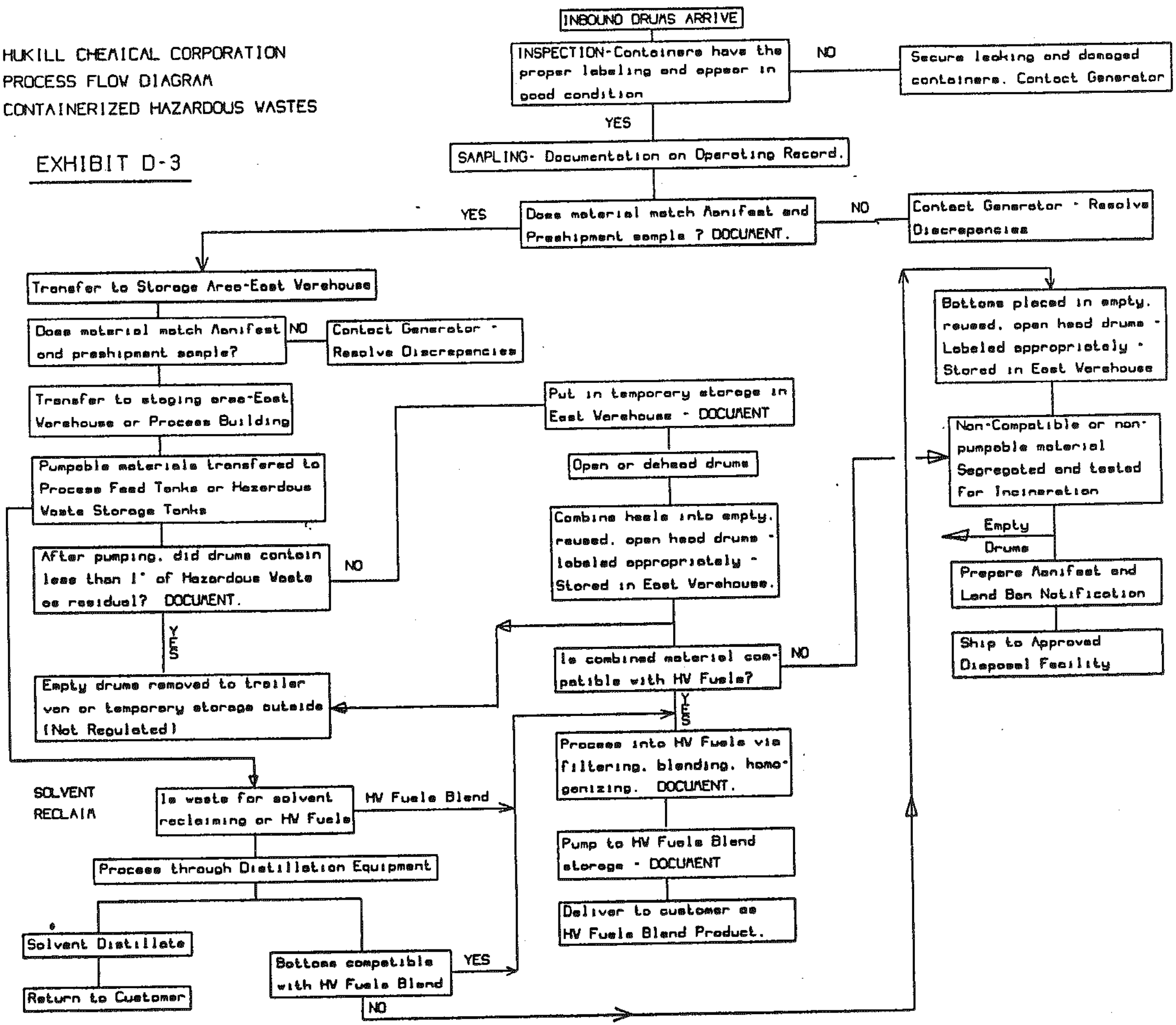
\SITEDWGS\PLOT001G.GCD 2/8/89; Rev. 8/17/95

SCALE: 1" = 14'

Revision I. 9/1/88

# HUKILL CHEMICAL CORPORATION
# PROCESS FLOW DIAGRAM
# CONTAINERIZED HAZARDOUS WASTES

## EXHIBIT D-3



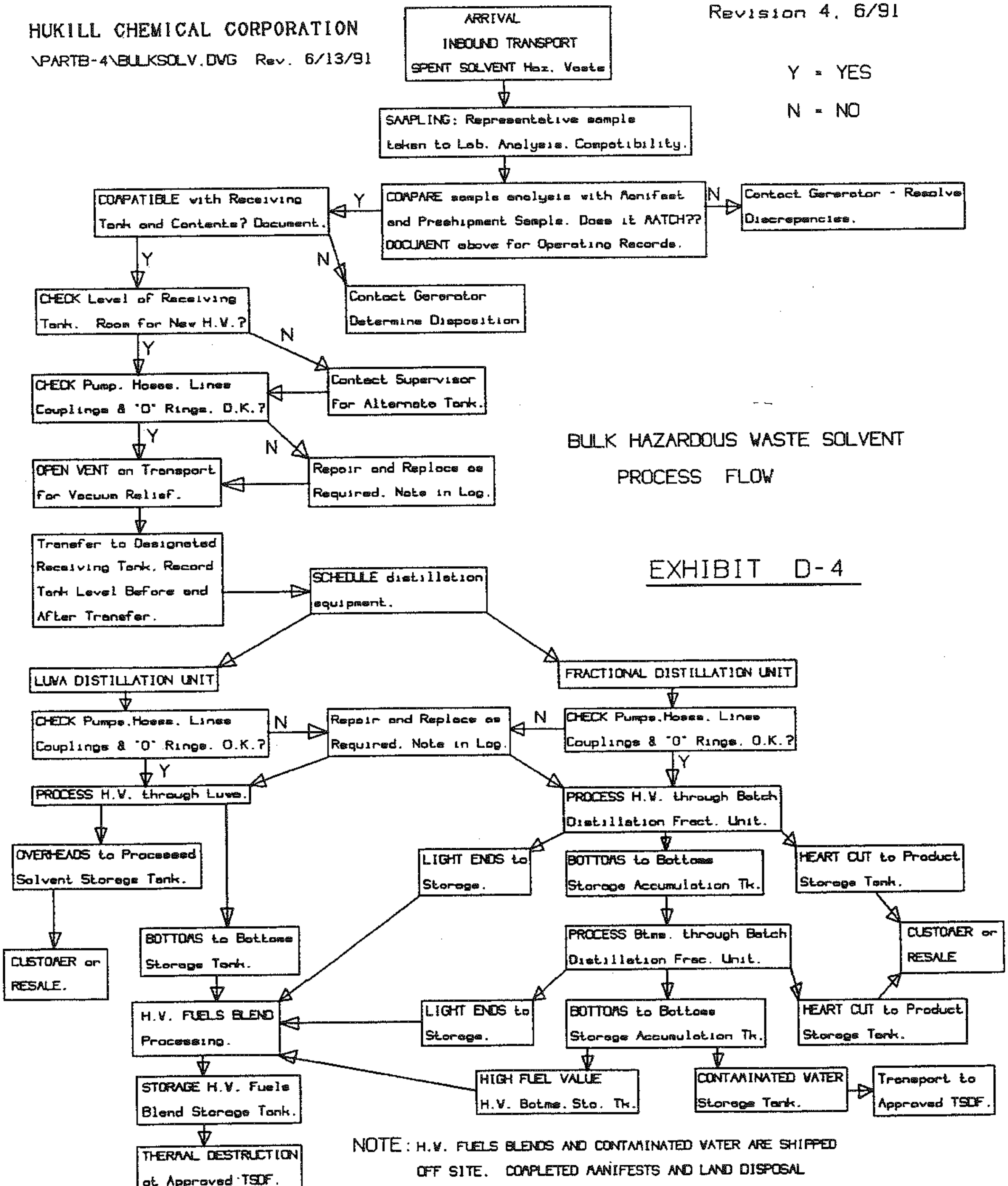
HUKILL CHEMICAL CORPORATION

\PARTB-4\BULKSOLV.DWG Rev. 6/13/91

Revision 4, 6/91

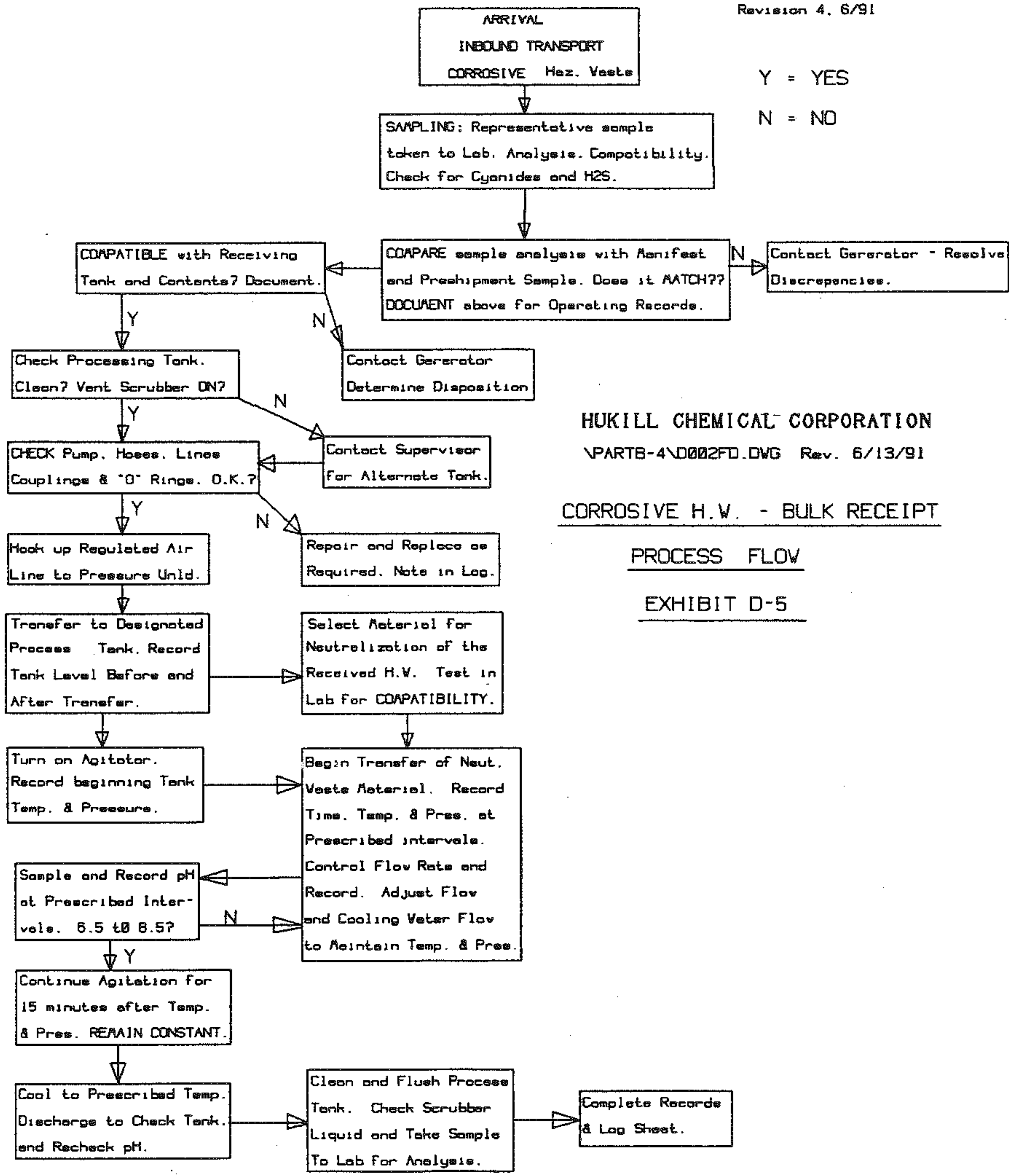
# BULK HAZARDOUS WASTE SOLVENT PROCESS FLOW

## EXHIBIT D-4




NOTE: H.W. FUELS BLENDS AND CONTAMINATED WATER ARE SHIPPED OFF SITE. COMPLETED MANIFESTS AND LAND DISPOSAL RESTRICTION FORMS ACCOMPANY SHIPMENTS.

Revision 4, 6/91




## HUKILL CHEMICAL CORPORATION

\PARTB-4\D002FD.DWG Rev. 6/13/91

## CORROSIVE H.W. - BULK RECEIPT

## PROCESS FLOW

## EXHIBIT D-5

Exhibit D-6

# EXHIBIT D-6

# EXISTING TANK SYSTEM ASSESSMENT

# FOR

# F-1 DIKE SYSTEM

# CONTAINING TANKS

# V-110M, V-210M, V-6000C and 13-15M

**Prepared March, 1996**

**By**

**Edgar M. Price, Engineering Consultant**

# TABLE OF CONTENTS FOR EXHIBIT D-6

# INTRODUCTION

Hukill Chemical Corporation (HCC) operates a chemical distribution and solvent recovery facility in Bedford, Ohio. HCC recycles industrial solvents using two thin film evaporators and a fractional distillation tower. HCC operates under RCRA interim status as a hazardous waste storage facility and has applied for a RCRA Part B Permit.

The F-1 Dike is located on the east side of the Processing Building and is 56 feet long, north/south direction, and 19 feet wide, east/west direction. The F-1 Dike system contains four tanks that store hazardous waste. Three of these tanks, V-110M,. V-210M and V-6000C, are permitted tanks because they sometimes receive hazardous waste generated off-site. The fourth, 13-15M, is a less-than-90-day generator tank which stores H.W. Fuels Blend, generated by HCC, prior to shipment to cement kilns for use as supplemental fuel.

Three of these tanks, V-110M, V-210M and 13-15M, are equipped with slow-speed agitators to keep the solid particles suspended. All four of the tanks have either cone or dish bottoms.

The capacities of these tanks are as follows:

| Tank Identification | Liquid Capacity - gallons | |
|---|---|---|
| V-110M | 9,500 | permitted tank |
| V-210M | 10,000 | permitted tank |
| V-6000C | 6,000 | permitted tank |
| 13-15M | 15,000 | less-than-90-day tank |

This assessment is prepared at the request of OEPA to present more detailed and current information on the F-1 Dike System. It is recognized by the OEPA that this is considered an "existing" system rather than a "new" system. Therefore, the OAC 3745-55-91 rules apply to this system.

# TANK SYSTEM DESCRIPTION

1. Storage Tanks

This tank system consists of four tanks, only three of which are permitted hazardous waste storage tanks. **Figure 1**, "F-1 DIKE - PLAN VIEW", found on the following page, provides the location of the individual tanks within the containment dike. All these tanks may contain flammable solvents at any given time. The tank system is designed for flammable liquid storage. It meets NFPA guidelines.

a) V-110M Tank

V-110M is a carbon steel, vertical, dish bottom tank with a 9' 6" diameter and an overall height of 24 feet. This tank has a steel support skirt around the bottom of the tank and up to the straight sides. 3" x 3" x 1/4" carbon steel angles are welded to the both sides of the bottom of the skirt. These angles are bolted into the concrete pedestal. The tank is equipped with four baffles and a slow speed top mounted agitator which rests on steel channels that extent across the top of the tank.

The original shell and dish thickness were, apparently, 1/4 inch. This tank was purchased used and is of unknown age.

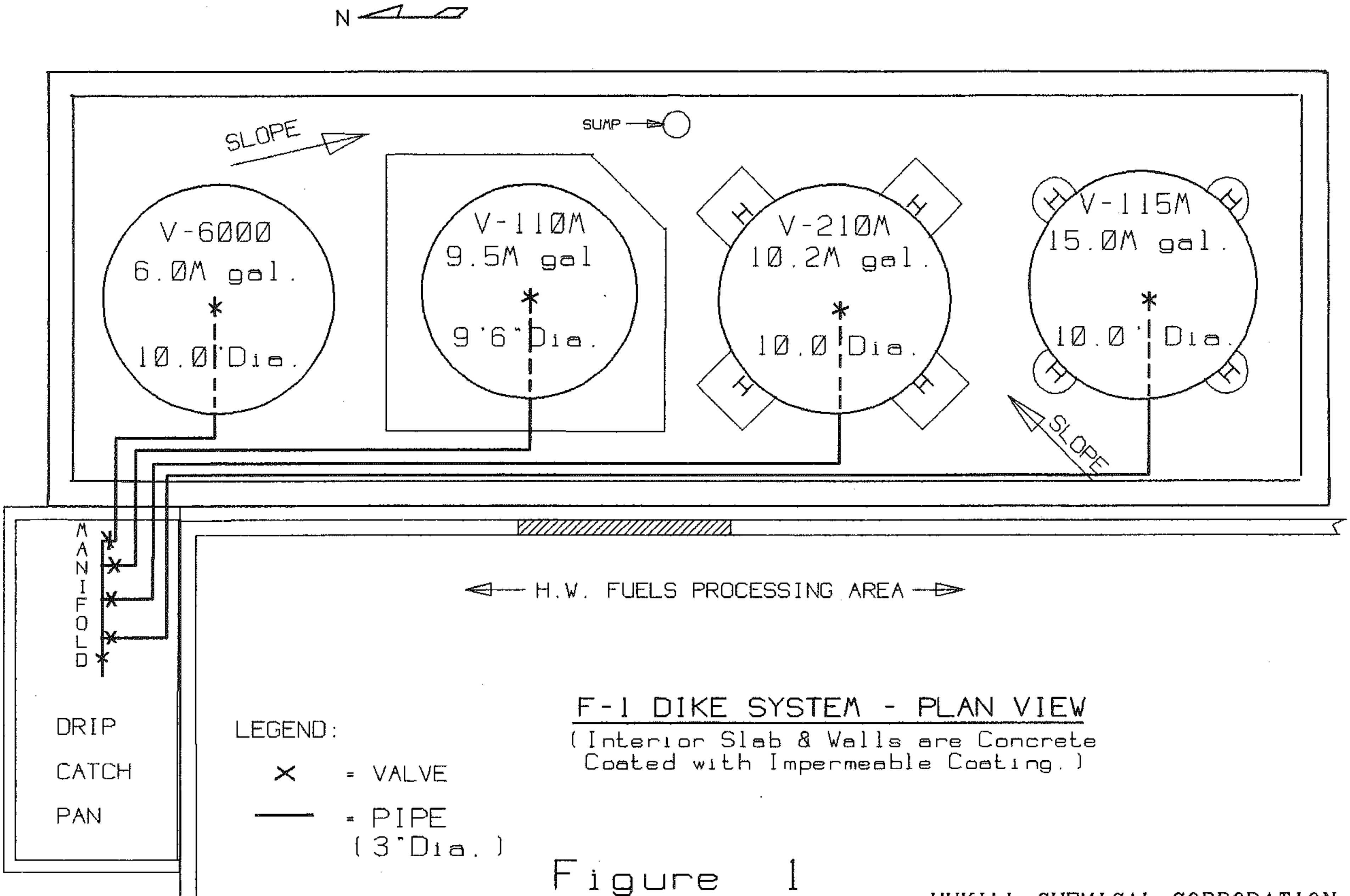
b) V-210M Tank

V-210M is a carbon steel, vertical, cone bottom tank with a 10' 0" diameter and an overall height of 26' 6". The tank is supported by four W8 x 35 H beams welded to 1/4" plates which are welded to the straight side of the tank. These columns have a one foot square by 3/4" plate welded to the bottom of each. These base plates are bolted with one inch bolts to the concrete pad. The tank is equipped with four baffles and a slow speed top mounted agitator which rests on steel channels that extent across the top of the tank.

The original shell and cone thickness were, apparently, 1/4 inch and 5/16 inch, respectively.

c) V-6000C

V-6000C is a carbon steel, vertical, cone bottom tank with a 10' 0" diameter and an overall height of 16' 9". The original shell and cone thickness of this tank were 1/4 inch. The tank is supported by six columns of 5" x 5" x 1/2" steel angles with 1" thick steel base plates at the bottom of each column. The six columns are also tied together circumferentially with a welded continuous angle of 3" x 3" x 1/4" thick. There is no agitator for V-6000C tank.




F-1 DIKE SYSTEM - PLAN VIEW

(Interior Slab & Walls are Concrete Coated with Impermeable Coating.)

Figure 1

HUKILL CHEMICAL CORPORATION

\PARTB-10\F-1PLOT.GCD Rev. 6/28/95

Scale : 1" = 6'

d) 13-15M

13-15M is a carbon steel, vertical, cone bottom tank with a 10' 0" diameter and 32' 0" overall tank height. The tank is supported by four 8" x 8" steel columns welded to the tank with a steel plate welded to the bottom of each plate. These four plates mount onto four steel reinforced concrete columns of four feet in height. The distance from the straight side of the tank to the bottom of the support plate, at the concrete column top, is about 10 inches. The four steel plates are bolted to the concrete columns with 3/4 inch bolts. This tank is equipped with four baffles and a slow speed, top-mount agitator supported by C12x25 steel channels which are welded to the roof and span the top.

The above four tanks all operate at atmospheric pressure and are equipped with flame arrestors and conservation vents. Each tank will be equipped with a high level probe connected to a high level alarm to prevent overfilling. Tank filling and emptying is manually controlled. Tank overflows are prevented with a manual shut-off system. The description of the high level alarm system, manufactured by Princo Instruments, Inc., which HCC plans to install on each of these tanks is found in Appendix A. Each tank is grounded to prevent static electricity.

2. Ancillary Equipment

The fill/discharge piping for all four tanks in this dike system are 3 inch diameter, Schedule 40, carbon steel. Piping connections are threaded or flanged. Valves are threaded body gate or ball valves with working pressure of at least 140 psig. Hoses and portable pumps are used for transfers. All hoses are either metal reinforced elastomer or all-metal (steel) flexible hoses with quick release OPW type fittings. Hoses and fittings are rated for 100 psig.

**Figure 1**, page 5, shows the general location of the fill/discharge piping for these four tanks. Piping supports, not shown, are placed at 10 to 12 foot intervals and rest on the concrete slab.

Portable, positive displacement pumps, designed to meet Class 1, Group D, Division 1 electrical rating, are used to transfer the waste. The pumps are located within spill containment pans adjacent to the containment area. Quick disconnect couplings are used to connect the piping to the pumps. A transfer station has been installed within a stainless steel catch pan. This is located at the north end of the Processing Building and contains a pipe and valve manifold, stationary pump and strainer for transferring to and from the four tanks in this F-1 Dike System. This is a housekeeping improvement being implemented by HCC.

3. Secondary Containment

a) Description

All four hazardous waste tanks, the three permitted tanks and the less-than-90-day generator tank, 13-15M, are located in the 17' x 54' containment area of the F-1 Dike. This dike was constructed in the early eighties by adding a 7 inch, steel reinforced concrete slab and constructing dike walls of 12" Ivany block, with vertical and horizontal rebar, on a 3 foot deep concrete footer. The wall was then capped with a 3 1/2" thick concrete cap.

The dike walls and slab are coated with Siloxirane C2033. This coating was recommended by the manufacturer and passed HCC's testing. HCC's testing was half immersion of a sample coupon in a sealed bottle containing a mixture, by volume, of 80% methylene chloride and 20% acetone for greater than 24 hours without significant swelling, softening, weight gain or deterioration. The sample survived with less than 1 % weight gain, less than 1% increase in length, width or thickness and within 5 Shore Durometer D units of the as-received sample. There was no apparent affect on the surface or color of the coating. The sample was in the same condition after 10 days. Most samples failed the 24-hour test.

The structural assessment for both the dike slab and the containment walls are found in Appendix A of this exhibit.

b) Containment Capacity

The minimum spill containment required by OAC 3745-55-93(E)(1)(b) for the F-1 Dike is the volume of the largest storage tank within the dike, 15,000 gallons, and the 25-year, 24-hour rainfall of 4 inches. The Secondary Containment Calculations are found in Appendix B of this exhibit. They demonstrate that the dike has a containment capacity of 2,812 cubic feet and the required volume is 2,364 cubic feet. Therefore, the F-1 Dike exceeds the required minimum containment by 448 gallons.

## DESIGN STANDARDS

Aside from being constructed of welded carbon steel, no references to design standards were found for the construction of these cone bottom tanks. Hamilton Welding, the manufacturer of the 13-15M tank, advised that they usually follow UL 142 design standards, but HCC required a cone bottom tank. Hamilton Welding advised that UL 142 tank standards do not cover cone bottom tanks. The ultrasonic test results of the tank wall thickness tests for these tanks, submitted by Professional Service Industries, Inc., are provided in Attachment B of Section D.

## WASTE COMPATIBILITY

The hazardous wastes stored in the subject tanks have the characteristics of Toxicity and Ignitability. The carbon steel tanks and ancillary equipment are compatible with the waste stored. The material used to coat the inside of the containment area was tested by both the manufacturer and HCC and found to be compatible with the constituents of the wastes to be stored in the system.

## CORROSION PROTECTION MEASURES

HCC has maintained a protective coat of paint on these tanks and on the supporting steel for the cone bottom tanks. As stated in the Waste Analysis Plan, the Acid Value or pH is obtained on incoming hazardous waste destined for this tank system. If the waste has the characteristic of Corrosivity, it will be neutralized prior or during transfer to the storage tank. HCC also periodically has the thickness of the storage tanks measured by an outside testing service to be sure that the tank thickness is within safe operating limits.

These tanks will not be in contact with the soil or water. The structural steel supports will keep the tanks out of rainwater collected in the dike. Therefore, the requirements of 3745-55-92(A)(3) do not apply to this system.

## STRUCTURAL ASSESSMENTS

1. Tanks

Appendix A contains the structural calculations for the four tanks in this dike. HCC contracted S.M. Haw Associates to prepare the structural analysis. They have provided structural engineering expertise for HCC since 1988. Please note that the structural calculations in Appendix A of this exhibit are grouped by type of tank. The page numbering starts over for each type of tank.

The "service factor" is defined as the actual minimum thickness measurement divided by the calculated minimum thickness. The calculated minimum thickness includes the allowable working stress of the material. I. e., a service factor of 1.0 represents a tank shell loaded to its full allowable stress.

The minimum measured shell thickness for V-110M provides a service factor of 3.75 per page 3 of Appendix A. V-110M will be taken out of service when the service factor reaches 1.5 (0.104 inches) or when pinhole leaks begin appearing.

The minimum measured cone thickness for this tank provides a service factor of 0.74. However this tank has been in service for many years with no apparent structural deficiency. We believe that the formula used to determine the minimum required cone plate thickness is not accurate for flat cones. The required cone plate thickness approaches infinity as the cone becomes flat. This tank is on the Weekly Inspection check list and will be observed for signs of failure.

The minimum measured shell thickness for V-210M provides a service factor of 4.94 per page 3 of Appendix A. V-210M will be taken out of service when the service factor reaches 1.5 (0.861 inches) or when pinhole leaks begin appearing.

The minimum measured cone thickness for this tank provides a service factor of 3.32. V-210M will be taken out of service when the service factor for the cone plate reaches 1.5 (0.1017 inches) or when pinhole leaks begin appearing.

The minimum measured shell thickness for V-6000C provides a service factor of 7.25 per page 3 of Appendix A. V-6000C will be taken out of service when the service factor reaches 1.5 (0.0492 inches) or when pinhole leaks begin appearing.

The minimum measured cone thickness for this tank provides a service factor of 5.13. V-6000C will be taken out of service when the service factor for the cone plate reaches 1.5 (0.0696 inches) or when pinhole leaks begin appearing.

The minimum measured shell thickness for 13-15M provides a service factor of 3.67 per page 3 of Appendix A. 13-15M will be taken out of service when the service factor reaches 1.5 (0.0861 inches) or when pinhole leaks begin appearing.

The minimum measured cone thickness for this tank provides a service factor of 0.42. However this tank was constructed for HCC in 1992 and has no apparent structural deficiency. We believe that the formula used to determine the minimum required cone plate thickness is not accurate for flat cones. The required cone plate thickness approaches infinity as the cone becomes flat. This tank is on the Weekly Inspection check list and will be observed for signs of failure.

a.) Seismic Considerations

The seismic considerations calculate the forces applied to a fully loaded tank according to the guidelines of the Ohio Basic Building Code.

The calculations in Appendix A demonstrate that the factor of safety is 12.5 against seismic overturning for V-110M tank.

The calculations in Appendix A demonstrate that the factor of safety is 3.0 against seismic overturning for V-210M tank.

The calculations in Appendix A demonstrate that the factor of safety is 5.8 against seismic overturning for V-6000C tank.

The calculations in Appendix A demonstrate that the factor of safety is 3.1 against seismic overturning for 13-15M tank.

b.) Wind Considerations

The wind overturning considerations calculate the forces applied to an empty tank according to the guidelines of the Ohio Basic Building Code.

The calculations in Appendix A demonstrate that the factor of safety against wind overturning the V-110M tank is 1.57.

The calculations in Appendix A demonstrate that the factor of safety against wind overturning the V-210M tank is 1.24 prior to considering the added stabilization of the anchor bolts.

The calculations in Appendix A demonstrate that the factor of safety against wind overturning the V-6000C tank is 2.30.

The calculations in Appendix A demonstrate that the factor of safety against wind overturning the 13-15M tank is 1.2 prior to consideration of the added safety due to the anchor bolts.

c.) Frost Heave

The calculated factor of safety against overturning the V-110M tank in a high wind with frost heave elevating one side of the tank is 1.52. The dead weight of the empty tank is used for this calculation.

The calculated factor of safety against overturning the V-210M tank in a high wind with frost heave elevating one side of the tank is 1.16 prior to consideration of the added safety due to the use of anchor bolts.

The calculated factor of safety against overturning the V-6000C tank in a high wind with frost heave elevating one side of the tank is 2.22.

The calculated factor of safety against overturning the 13-15M tank in a high wind with frost heave elevating one side of the tank is 1.13 prior to considering the added safety due to the use of anchor bolts.

2. Foundation

a.) Full Tanks

V-110M tank filled with liquid of 1.33 specific gravity would create a bearing pressure of 2,061 pounds per square foot (psf) on the soil. The soil has a bearing capacity of 4,000 psf. Calculations demonstrating this are provided on page 8, Appendix A of this exhibit. The 1.33 specific gravity, 82.98 lb./cu.ft., is the highest density liquid HCC would expect to place in the spent solvent storage tanks.

V-210M tank filled with liquid of 1.33 specific gravity would create a bearing pressure of 3,302 pounds per square foot (psf) on the soil under each tank leg. The soil has a bearing capacity of 4,000 psf. Calculations demonstrating this are provided on page 11, Appendix A of this exhibit.

V-6000C tank filled with liquid of 1.33 specific gravity would create a bearing pressure of 1,613 pounds per square foot (psf) on the soil. The soil has a bearing capacity of 4,000 psf. Calculations demonstrating this are provided on page 9, Appendix A of this exhibit.

13-15M tank filled with liquid of 1.33 specific gravity would create a bearing pressure of 3,857 pounds per square foot (psf) on the soil. The soil has a bearing capacity of 4,000 psf. Calculations demonstrating this are provided on page 9, Appendix A of this exhibit.

3. Secondary Containment

The requirement that the F-1 Dike be structurally capable of containing the spill of the largest tank plus the 25 year, 24 hour rainfall of four inches has been demonstrated. In fact, the calculations provided in Appendix A of this exhibit demonstrate a factor of safety of 3.6 for the dike full of liquid with a specific gravity of 1.33.

**Certification Statement for Written Assessment for the Design of the Tank System**

I attest that I am an independent, qualified, registered professional engineer.

I have reviewed the attached F-1 Dike System written assessment and I attest in writing that the tank system has sufficient structural integrity and is acceptable for the storage of hazardous waste.

The assessment shows that the foundation, structural support, seams, connections, and pressure controls are adequately designed and that the tank system has sufficient structural strength, compatibility with the waste(s) to be stored or treated and corrosion protection to ensure that it will not collapse, rupture, or fail.

The assessment includes, at a minimum, the following information:

(1) Design standards according to which tank(s) and/or the ancillary equipment are constructed,

(2) Hazardous characteristics of the waste(s) to be handled,

(3) For new tank systems or components in which the external shell of a metal tank or any external metal component of the tank system will be in contact with the soil or with water, a determination by a corrosion expert of:

  (a) Factors affecting the potential for corrosion,
  (b) The type and degree of external corrosion protection that are needed to ensure the integrity of the tank system during the use of the tank system or components,

(4) Design considerations to ensure that:

  (a) Tank foundations will maintain the load of a full tank, and
  (b) Tank system will withstand the effects of frost heave.

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Professional Seal

STATE OF OHIO
STANLEY
M.
HAW
24218
REGISTERED
PROFESSIONAL ENGINEER

Signature of the Registered Professional Engineer

Stanley M. Haw

## TANK SYSTEM INTEGRITY EXAMINATION

1. External Inspection

An external inspection of this tank system and its components was completed by S.M. Haw Associates, Inc. in December, 1995. The tank system was in operation and there were no signs of weld breaks, punctures, coating failure, cracks or corrosion. There were no leaks at fittings, access manways, welds, valves or piping.

The concrete slab and dike walls were clean and free of visible spills. The impermeable coating lining the walls and slab appeared to be intact.

2. Non-Destructive Testing

Ultrasonic thickness measurements were made on all four tanks within this dike system in June, 1994. The results of these tank wall thickness measurements are provided in Attachment B of Section D.

3. Tightness Testing

No further tightness testing should be required at this time, since this system is presently in operation and there are no leaks from the tanks.

4. Ancillary Equipment

The pipes, valves and fittings comprise the ancillary equipment. As stated above, there are no leaks or evidence of leaks and the ancillary equipment appears to be is good condition. The new transfer station is being used to provide solid piping from the pump to the storage tank within the F-1 Dike. The transfer station is placed within a stainless steel containment pan. The use of the transfer station should reduce the use of portable pumps and frequent strainer cleaning of the small portable pump basket screens.

## CERTIFICATION for INSTALLATION

Since the F-1 Dike System is considered an "existing" system, a certification of installation is not required.

# APPENDIX A

# STRUCTURAL CALCULATIONS

Structural Assessment of a Hazardous Waste Storage Tank
for Hukill Chemical Company
*by S. M. Haw Associates, Inc.*
*Professional Engineers*

November 10, 1995

**1. Description** [C]

*Hazardous Waste Dike Identification*:.....F-1 Fuels Dike System
*Tank Designation*:....................................V-110 M
*Rated Capacity*:.........................................9,500 Gallons each tank
*Specific Gravity of Contained Liquid*: .....1.33 (Maximum Use)
*Part B Application, Section D Location*: .Exhibit D-6
*Tank Construction*: .Vertical, welded steel plate with flat cone and circular skirt bottom [1.6]
*Design Standard:* .............None
*Material Specifications*:...Shell, Assumed Minimum ASME SA 515 Grade 55 carbon steel [2.1]
*Tank Dimensions*: ............Cyl. Shell Height: 19'-1" Shell Diameter (O.D.): 9'-6" [1.6]
Bottom Cone Height: 1'-0" Shell Thickness (Design): 1/4"
Total Height: 24'-0"

*Tank Shell Thickness Measurements:*

| | | |
|---|---|---|
| Minimum measured shell, top: | 0.258 inches | [3.9] |
| Minimum measured shell, upper: | 0.267 inches | |
| Minimum measured shell, lower: | 0.260 inches | |
| Minimum measured shell, bottom: | 0.268 inches | |

**2. Weight of Tank Shell**

Cylindrical Shell Area: $A = \pi \times d \times h$ [4]
$= 3.1416 \times 9'\text{-}6" \times 24.00 = 716.3$ sq. ft
Cylindrical Shell Weight: $Wt = A \times$ (pl. wt.) [8.1]
$= 716.3 \times 10.2$ lbs./sq. ft. (1/4") = 7,306 lb

Top Area: $A = \pi \times d^2/4$ [5]
$= 3.1416\ (9'\text{-}6")^2\ /\ 4 = 70.9$ sq. ft.
Top Weight: $Wt = A \times$ (pl. wt.) [8.1]
$= 70.9 \times 10.2$ lbs./sq. ft. (1/4") = 723 lb

Top Channels: $2 - C9 \times 15 \times 9'\text{-}6" = 19'\text{-}0" \times 15$ plf = 285 lb
Top Plate: $A = (24\ 1/2" \times 18") - (\pi \times (10")^2\ /\ 4)$ [5]=362 sq. in.=2.52 sq. ft.
$Wt = A \times$ (pl. wt.) [8.1]
$= 2.52$ sq. ft. $\times 40.8$ lbs./sq. ft. (1") 103 lb

Bottom Cone Slant Height: $c = \sqrt{a^2 + b^2}$ [6]
$= \sqrt{(9'\text{-}6"/2)^2 + (1'\text{-}0")^2} = 4.85'$

| | | |
|---|---|---|
| Bottom Area: | $A = 1/2 \times \pi \times d \times s$ | [7] |
| | $= 1/2 \times 3.1416 \times 9'\text{-}6'' \times 4.85 = 72.4$ sq. ft. | |
| Bottom Weight: | $Wt = A \times$ (pl. wt.) | [8.1] |
| | $= 72.4 \times 10.2$ lbs./sq. ft. (1/4") = | 739 lb |
| Bottom Angles Weight: | 2 Angles $3 \times 3 \times 1/4$ (4.9 plf) | [17-pg. 1-49] |
| | Circumference: $\pi \times d$ | [5] |
| | $= \pi \times 9'\text{-}6'' = 29.8$ | |
| | $Wt = 2 \times 4.9 \times 29.8$ | 292 lb |
| Weight of Miscellaneous Appurtenances: | | 500 lb |
| TOTAL WEIGHT OF TANK: | | 9,448 lb |

**3. Weight of Contained Liquid**

| | | |
|---|---|---|
| Volume of cylinder: | $V = \pi \times {d^2}/{4} \times ht$ | [4] |
| | $= \pi \times (9'\text{-}6'')^2 / 4 \times 19'\text{-}1'' = 1{,}353$ cu. ft. | |
| Weight of liquid: | $Wt = Vol \times 62.4 \times$ sp. gr. | |
| | $= 1353 \times 62.4 \times 1.33 =$ | 112,288 lb |
| Volume of Cone: | $V = 1/3 \times \pi \times d^2 / 4 \times ht$ | [7] |
| | $= 1/3 \times \pi \times (9'\text{-}6'')^2 / 4 \times 1'\text{-}0'' = 24$ cu. ft. | |
| Weight of Liquid in Cone: | $Wt = Vol. \times 62.4 \times$ sp. gr. | |
| | $= 24 \times 62.4 \times 1.33 =$ | 1,992 lb |
| TOTAL WEIGHT LIQUID | | 114,280 lb |

**4. Tank Supports**

Tank is full bottom bearing on skirt on concrete slab. Skirt has inside and outside angles 3" × 3" × 1/4".

Total Weight Tank & Liquid: 9,448 lb + 114,280 lb= 123,728 lb

Area of bottom skirt: $Area_T = A_1 - A_2 = \pi \times d_1^2 / 4 - \pi \times d_2^2 / 4$ [5]

$d_1 = (9'\text{-}6'') + (3'' + 3'') = 10'\text{-}0''$

$d_2 = (9'\text{-}6'') - (1/4'' + 1/4'' + 3'' + 3'') = 8'\text{-}11\ 1/2''$

$Area_T = \pi\ (10'\text{-}0'')^2 / 4 - \pi\ (8'\text{-}11\ 1/2'')^2 / 4 = 15.5$ sq. ft .=2,232 sq. in.

Force on Base: $\dfrac{P(lb)}{A(sq.in.)} = \dfrac{123{,}728}{2{,}232} = 55$ lb/sq. in. < 700 psi allowable bearing on concrete.

Structural Assessment of a Hazardous Waste Storage Tank
for Hukill Chemical Company
F-1 Fuels Dike System - Tank V-110M

**5A. Calculation of Required Tank Wall Thickness -- Cylindrical Shell**

A. Shell Tension

$T_h = 2.60 \times h \times D \times g$ [11-Eq. 3]

$T_h$ = Shell Tension, at depth h (lbs per inch)
h = Depth from top of tank (ft.)
D = Diameter of tank (ft.)
g = Specific gravity of contained liquid

At h = 19'-1" from top of tank

$T_h = 2.60 \times 19'\text{-}1" \times 9'\text{-}6" \times 1.33 = 627$ lbs/in.

B. Minimum Shell Thickness

$t_h = T_h / (f \times E)$ [11-Eq. 4]

$t_h$ = Minimum required shell plate thickness (inches)
$T_h$ = Shell Tension, at depth h (lbs per inch)
f = Allowable unit stress (13,700 psi) [2.1]
E = Joint efficiency (0.66) [11-Table 1]

At h = 19'-1" from top of tank

$t_h = 627 / (13{,}700 \times 0.66) = 0.0693$ in.

Minimum measured thickness = 0.268 in.

Service Factor (SF) = $\dfrac{t_{actual}}{t_{required}} = \dfrac{0.260}{0.0693} = 3.75 \therefore$ The cylindrical shell is OK

**5B. Calculation of Required Wall Thickness-Flat Cone**

Longitudinal (Meridional) Stress atSpring Line

$$\sigma_1 = \frac{qR}{2t\cos\alpha}$$ [23-pg 449]

Hoop (Circumferential) Stress at Spring Line

$$\sigma_2 = \frac{qR}{t\cos\alpha}$$ [23-pg 449]

Using hoop stress as maximum, calculate minimum ±

$$t_h = \frac{qR}{\sigma_2 \cos\alpha}$$

$t_h$ = Minimum required cone plate thickness (inches)
q = Internal pressure (psi)
= (Weight of liquid)(height)
R = Maximum radius of cone (inches)
$\sigma_2$ = (f)(e)
f = Allowable unit stress (psi) [2.1]
e = Joint efficiency factor (0.66) [11-Table 1]
$\alpha$ = Cone apex angle (degrees)
$\tan^{-1} = R/hc = \tan^{-1}(9'\text{-}6''/2)/1'\text{-}0'' = 78.11$ degrees
hc = Height of cone (inches)

$$t_h = \frac{(62.4 \times 1.33 \times 19'-1'')/(144) \times (9'-6''/2 \times 12)}{(13{,}700)(0.66)(\cos 78.11)} = 0.3365 \text{ inches}$$

Design Cone Thickness: 1/4" [3.11]

Service Factor (SF) = $\frac{t_{actual}}{t_{required}} = \frac{0.250}{0.3365} = 0.74$

Conclusion: Service Factor (SF) of flat cone bottom is below the value of one (1.00). Since this tank is currently in service with no apparent structural deficiency, we recommend continuation of present usage with Hukill Chemical to monitor this area for future indication of distress.

## 6. Calculation of Seismic Forces on the Tank

A. Seismic Formula -- Seismic Zone #1 (Ohio) [Ohio Basic Building Code = OBBC]
$V = 2.5\ A_v\ I\ K\ C\ S\ W$ [OBBC 1113.4]

V = Lateral Seismic Force (lbs)
$A_v$ = 0.075 (Coefficient for Ohio) [OBBC 1113.4.1]
I = Importance Factor (For industrial plants, I = 1.0) [OBBC 1113.4.2]
K = Horizontal Force Factor (For a tank on ground, K = 1.0) [OBBC 1113.4.3] [& OBBC 1113.9.3]
C S = Coefficient combination (For zones 0, 1 & 2, CS = 0.14) [OBBC 1113.4.4]
W = Weight of the fully loaded tank (lbs)

$V = 2.5 \times 0.075 \times 1.0 \times 1.0 \times 0.14 \times (9{,}448 \text{ lbs} + 114{,}280 \text{ lbs}) = 3{,}248$ lbs

B. Overturning Moment Due to Seismic Force

OTM = V /1000 × arm

OTM = Overturning Moment about base (ft. kips)

arm = Vertical Distance from the base to center of gravity of loaded tank(ft.)

OTM = 3,248 lbs/1000 lbs/kip × (19'-1")/2 + (4'-11") = 47.0 ft. kips

C. Resisting Moment of the Tank -- Full Tank

RM = W /1000 × delta

RM = Resisting Moment (ft. kips)

delta = Horizontal Distance from center of the tank to its overturning point (diam./2)

RM = (9,448 lbs + 114,280 lbs) /1000 lbs /kip × (9'-6") /2 = 587.7 ft. kips

D. = Factor of Safety Against Seismic Overturning

Factor of Safety (FOS) = RM / OTM = 587.7 / 47.0 = 12.5

Since FOS is greater than 1.5, tank is safe against overturning from seismic forces.

**7. Calculation of Wind Forces on the Tank** [Ohio Basic Building Code = OBBC]

A. Wind Formula -- 80 mph wind zone -- Exposure B

$P_d = P_e \times I^2 \times C_p$ [OBBC 1112.3]

Definitions as follows: [OBBC 1112.2]

$P_d$ = Design Wind Pressure (lbs per sq. ft.)

$P_e$ = Effective Velocity Pressure - Exposure B ($P_e$ = 13psf) [OBBC Table 1112.3.3a ]

I = Importance Factor for Service (I = 1.0) [OBBC Table 1112.2a(1)]

$C_p$ = External Pressure Coefficient for Round Tanks (0.8) [OBBC Table 1112.2d ]

For h/D = 24'-0" / 9'-6" = 2.53, $C_p$ = 0.8

$P_d = 13 \times (1.0)^2 \times 0.8 = 10.4$ psf

B. Wind Force on Tank

$P = P_d \times$ Wind Area

Wind Area = D × h = 9'-6" × 24'-0" = 228.0 sq. ft.

D = Tank Diameter (ft.)

h = Tank Height (ft.)

P = 10.4 × 228.0 = 2,371 lbs.

C. Overturning Moment due to Wind Force

OTM = P /1000 × arm

arm = Vertical Distance from the base to center of gravity of the wind area (ft.)

OTM = 2,371 lbs /1000 lbs/kip × (24'-0") /2 = 28.5 ft. kips

D. Resisting Moment of Tank -- Empty Tank

RM = DL / 1000 × delta

RM = Resisting Moment (ft. kips)
DL = Dead Load of Tank (Weight of empty tank) (lbs)
delta = Horizontal Distance from center of tank to its overturning point (diam /2)

RM = 9,448 lbs /1000 lbs/kip × (9'-6") /2 = 44.9 ft. kips

E. Factor of Safety Against Wind Overturning

Factor of Safety (FOS) = RM / OTM = 44.9 / 28.5 = 1.57

Since FOS is greater than 1.5, tank is safe against overturning from wind forces.

**8. Frost Heave** [14.3c]

Maximum frost design depth per local Building Code in this area is 30 inches.

Assuming the underlaying soil is completely saturated with water and had frozen solid and using an expansion factor of water to ice as 10%, the frozen area would rise 30 inches x 0.10 or 3 inches above an unfrozen area.

The tanks of this dike system all set directly upon an 7 inch thick reinforced concrete slab poured over an existing 6" concrete slab-on-grade. The containment slab is 19'-0" wide x 59'-0" long

Assuming the maximum condition where the narrow side of the slab-on-grade has 30 inches of water under it, and the other side has 30 inches of ice, the differential due to frost heave would be 3 inches vertical movement in 30'-0" horizontal distance.

# Structural Assessment of a Hazardous Waste Storage Tank for Hukill Chemical Company

## F-1 Fuels Dike System - Tank V-110M

### A. Proportion to find differential elevation of base:

$$\frac{V}{H} = \frac{Y}{h}$$

V = Vertical movement of slab (inches)
H = Horizontal length of slab (ft.)
Y = Vertical rise of tank edge (inches)
h = Horizontal distance between tank edges,
diameter of tank (ft.)

Y = (V/H) x (h)
= (3" / 19'-0") x (9'-6") = 1.500 inch vert. rise

### B. Proportion to find resulting offset of Center of Gravity of tank:

$$\frac{Y}{h} = \frac{X}{d}$$

X = Horizontal offset distance to center of tank (inches)
d = Vertical distance from base to center of tank (ft.)

X = (Y/h) x (d)
= (1.500" / 9'-6") x (24'-0")/2 = 1.8947 in. = 0.1579 ft.

### C. Calculate resulting Frost Resisting Moment:

FRM = DL x delta

FRM = <u>F</u>rost <u>R</u>esisting <u>M</u>oment (ft. kips)
DL = <u>D</u>ead <u>L</u>oad of Tank (Weight of empty tank) (lbs)
delta = Horizontal Distance from center of tank to its overturning point (ft.)

FRM = 9,448 lbs/1000 lbs/kip x [(9'-6") /2 - 0.1579] = 43.39 ft. kips

### D. Overturning Moment due to Wind Force [para. 7.C.]

OTM = 28.5 ft. kips

### E. Factor of Safety Against Overturning:

Factor of Safety (FOS) = FRM/OTM = 43.39/28.5 = 1.52 > 1.5
OK

**9. Foundation Investigation** [14.3]

The bottom of the containment area is a 7" reinforced concrete slab poured over an existing 6" concrete slab.

Area of bearing on soil: $A_T = A_1 - A_2 = \pi d_1^2 / 4 - \pi d_2^2 / 4$ [5]

$d_1$ =(9'-6") + (7") + (6") + (7") + (6") = 11'-8"

$d_2$ = (9'-6") - (1/4") - (7") - (6") - (1/4")-(7")-(6") = 7'-3 1/2"

$A_T = \pi$ (11'-8")$^2$ / 4 - $\pi$ (7'-3 1/2")$^2$ / 4 = 65.14 sq. ft.

$$\text{Force} = \frac{\Pr essure}{Area} = \frac{9{,}448 + 114{,}280}{65.14} =$$ 1,899 psf

The 7" and 6" base slabs produce a pressure of (7" + 6") /12" × 150 lbs/cu. ft.) 162 psf

Total soil pressure under tank 2,061 psf

Existing soil bearing [21]

Allowable soil bearing capacity 4,000 psf

The concrete base slab and the soil capacity is adequate to carry the tanks

**10. Containment Wall Investigation**

A. Construction [14.3]

12" wide x 16" long x 8" high "Ivany" concrete masonry block

Wall is 12" wide by 4'-0" maximum height

Vertical reinforcing consists of #4 bars at 8" on centers inside face, #4 bars at 16" on centers outside face

Horizontal reinforcing consists of #4 bars at 8" on centers, both faces

B. Wall Design [18]

$P = 1/2\ w\ h^2$

P = Force on wall due to the contained liquid pressure (lbs per ft. of length)

w = Weight of contained liquid (lbs / cubic ft.)

hd = Height of contained liquid (ft.)

P = 1/2 (62.4 × 1.33) × (4'-0")$^2$ = 663.9 lbs / ft.

$M = P \times 1/3\ h$

M = Moment at base of wall (ft. lbs / ft.)
P = Force on wall (lbs / ft.)
h = Height of contained liquid (ft.)

$M = 1/3 \times 663.9' \times 1/3\ (4'\text{-}0'') + 7'' = 1{,}272$ lbs / ft /1,000 lbs./kip = 1.27 ft. kips / ft.

$RM = A_s\ a\ d$ [Simplified concrete beam design function -- ] [American Concrete Institute publication --SP-3]

RM = Resisting Moment at base of wall (ft. kips / ft.)
$A_s$ = Area of reinforcing steel (sq. inches / ft.) -- (for #4 @ 8", $A_s = 0.30$) [15]
a = Coefficient of concrete design (for 24 ksi steel and 3 ksi concrete use 1.76) [16]
d = Distance from face wall to centerline of far reinforcing bar.

$RM = 0.30 \times 1.76 \times (11\ 5/8'' - 3'') = 4.55$ ft. kips / ft.

C. Factor of Safety of Containment Wall

Factor of Safety (FOS) = RM / M = 4.55 / 1.27 = 3.6
Since FOS is greater than 1.0, wall will safely contain the full height of 1.33 s.g. fluid.

# Structural Assessment of a Hazardous Waste Storage Tank for Hukill Chemical Company

*by S. M. Haw Associates, Inc.*

*Professional Engineers*

November 10, 1995

**1. Description** [C]

*Hazardous Waste Dike Identification*: .....F-1 Fuels Dike System

*Tank Designation*: ....................................V-210M

*Rated Capacity*: .......................................10,000 Gallons

*Specific Gravity of Contained Liquid*: .....1.33 (Maximum Use)

*Part B Application, Section D Location*: .Exhibit D-6

*Tank Construction*: .Vertical, welded carbon steel plate with cone bottom, 4 legs and internal baffles [1.7]

*Design Standard:* .............Labeled UL Spec. #142 [1.7]

*Material Specifications*: ...Shell, Assumed Minimum ASME SA 515 Grade 55 carbon steel [2.1]
Legs, Steel Beams ASTM A36

*Tank Dimensions*: .............Cyl. Shell Height: 15'-0" Shell Diameter: 10'-0" [1.7]
Bottom Cone Height: 6'-9" Shell Thickness (Design): 1/4"
Total Height: 26'-5 5/8" Cone Thickness (Design): 5/16"
Top Plate (Design): 5/16"

*Tank Shell Thickness Measurements:* ......Minimum measured shell, top: 0.240 inches [3.10]
Minimum measured shell, bottom: 0.255 inches
Minimum measured shell, cone: 0.296 inches

**2. Weight of Tank**

Cylindrical Shell Area: $A = \pi \times d \times h$ [4]

$= 3.1416 \times 10'\text{-}0" \times 15'\text{-}0" = 471.2$ sq. ft

Cylindrical Shell Weight: $Wt = A \times (\text{pl. wt.})$ [8.1]

$= 471.2 \times 10.2$ lbs./sq. ft. (1/4") = 4,806 lb

Top Area: $A = \pi \times d^2/4$ [5]

$= 3.1416 \times (10'\text{-}0")^2 / 4 = 78.5$ sq. ft.

Top Weight: $Wt = A \times (\text{pl. wt.})$ [8.1]

$= 78.5 \times 12.8$ lbs./sq. ft. (5/16") = 1,004 lb

Bottom Cone Area: $A = 1/2 \times c_1 + c_2 \times s$ [7-Eq. 55]

$s = \sqrt{a^2 + b^2}$ [6]

$$= \sqrt{(6'\text{-}9")^2 + \left(\frac{10'\text{-}0"}{2} - \frac{1'\text{-}6"}{2}\right)^2} = 8.87$$

$c_1 = \pi \times d_1$ [5]

$= \pi \times (10'\text{-}0") = 31.4$ lin. ft.

$c_2 = \pi \times d_2$ [5]
$= \pi \times (1'\text{-}6") = 4.7$ lin. ft.

$A = 1/2 \times (31.4 + 4.7) \times 8.87 = 160.1$ sq. ft.

| | | |
|---|---|---|
| Bottom Cone Weight: | Wt = A × (pl. wt.) [8.1] = 160.1 × 12.8 (5/16") = | 2,049 lb |
| Legs, Weight: | 4 Beams - W8 x 35 (35 plf) ×14'-3" = 57'-0" ft. × 35 = | 1,995 lb |
| | 4 Plates - 1/4" × 12" × 2'-2" = 8.67 sq. ft. × 10.2 (1/4) | 88 lb |
| | 4 Plates - 3/4" ×12" × 1'-0" = 4.00 sq. ft. × 30.6 (3/4) | 122 lb |
| Baffles | 3 Angles 2" × 2" × 1/4" × 6" = 1'-6" l.f. × 3.19 [17-pg. 1-50] | 4.8 lb |
| | 1 Plate 3/8" × 5" × 14'-10" = 6.18 sq. ft. × 15.3 [8.1]= | 94.6 lb |
| | 4 baffles × (4.8 lb. + 94.6 lb.) | 398 lb |
| Weight of Miscellaneous Appurtenances: | | 500 lb |
| TOTAL WEIGHT OF TANK: | | 10,962 lb |

## 3. Weight of Contained Liquid

Volume of tank above cone: $V = \pi \times d^2/4 \times ht$ [4]
$= \pi \times (10'\text{-}0")^2 /4 \times 15'\text{-}0" = 1{,}178$ cu. ft.

Weight of liquid above cone: $Wgt = Vol \times 62.4 \times$ sp. gr.
$= 1{,}178 \times 62.4 \times 1.33 =$ 97,765 lb

Volume of cone: $V = \frac{1}{3}(A_1 + A_2 + \sqrt{A_1 \times A_2})hc$ [7-Eq.55]

$A_1 = \pi \times (d_1)^2/4$ [5]
$= \pi \times (10'\text{-}0")^2 /4 = 78.5$ cu. ft.

$A_2 = \pi \times (d_2)^2/4$ [5]
$= \pi \times (1'\text{-}6")^2 /4 = 1.8$ cu. ft.

hc = height of cone = 6'-9"

$V = \frac{1}{3}(78.5 + 1.8 + \sqrt{78.5 \times 1.8})6'\text{-}9" = 207.4$ cu. ft.

Weight of liquid in cone: $Wgt = Vol \times 62.4 \times$ sp. gr.
$= 207.4 \times 62.4 \times 1.33 =$ 17,213 lb

Total Liquid Weight: 114,978 lb

**4. Check Tank Legs**

Tank Legs: Beam - W8 x 35 -- Length = 11'-5 5/8"
Area = 10.3 sq. in. -- Radius of gyration (y axis) = 2.03 in. [17-pg 1-32]

Total Weight of Tank & Liquid: 10,962 lb. + 114,978 lb. = 125,940 lb

Load on one leg: 125,946 lb. / 4 = 31,485 lb

Slenderness ratio: $K \times l / r_y$ = 2.0 (11.47' × 12)/2.03 = 136 [17-pg 5-42 & 5-135

Allowable Comp. Stress: $F_a$ (find from AISC Table 3-36) = 8.07 ksi [17-pg 3-16]
Actual Compressive Stress: $f_a$ = P/A = (31,485 lb./ 1000 lb./kip) /10.3 = 3.06 ksi < 8.07 ksi
Conclusion: Legs are OK

**5A. Calculation of Required Tank Wall Thickness -- Cylindrical Shell**

$$t_h = \frac{2.60 \times h \times d \times g}{f \times E}$$ [11-Eq. 4]

$t_h$ = Minimum required shell plate thickness (inches)
h = Depth from top of tank (feet)
d = Diameter of tank (ft.)
g = Specific gravity of contained liquid
f = Allowable unit stress (13,700 psi) [2.1]
E = Joint efficiency factor (0.66) [11-Table 1]

$$t_h = \frac{2.60 \times 15'\text{-}0" \times 10'\text{-}0" \times 1.33}{13{,}700 \times 0.66} = 0.0574 \text{ inches}$$

Minimum measured thickness = 0.255 inches

Service Factor (SF) = $\frac{t_{actual}}{t_{required}} = \frac{0.255}{0.0574} = 4.94$

Conclusion: The cylindrical shell is OK

**5B. Calculation of Required Tank Wall Thickness -- Cone**

Longitudinal Force at Spring Line

$$T_2 = \frac{\gamma}{2Cos\theta} \times \frac{D}{2} \times (X + \frac{D}{6} \times Cot\theta) \qquad [11\text{-Eq. } 32]$$

$T_2$ = Total Force (lb/ft.)
$\gamma$ = Density of liquid (pcf)
D = Tank Diameter (feet)
X = Distance from top of tank (feet)
hc = Height of cone

$$\theta = \text{Apex angle (degrees)} = \tan^{-1}\frac{D/2}{h_c} = \tan^{-1}\frac{(5'\!-\!0") - (9")}{6'\!-\!9"} \therefore \theta = 32.2° \qquad [6]$$

$$T_2 = \frac{(62.4 \times 1.33)}{2Cos32.2°} \times \frac{10.0}{2} \times (15.0 + \frac{10.0}{6} \times Cot32.2°) = 4{,}327 \text{ lb/ft.}$$

Hoop Force at Spring Line (Intersection of Shell and Cone)

$$T_1 = \frac{\gamma \times D \times X}{2\ Cos\theta} \qquad [11\text{-Eq. } 33]$$

$T_1$ = Total Force (lbs/ft.)
$\gamma$ = Desity of contained liquid (lbs/cu.ft.)
D = Tank diameter (feet)
X = Distance from top of tank (feet)
$\theta$ = Apex angle (degrees)

$$T_1 = \frac{(62.4 \times 1.33) \times 10.0 \times 15.0}{2Cos32.2°} = 7{,}356 \text{ lb/ft.} > 4{,}327 \text{ lb/ft.}$$

$$t_h = \frac{T_T}{f \times E} = \frac{7356/12}{13700 \times 0.66} = 0.0678 \text{ inches}$$ [11-Eq. 4]

$t_h$ = Minimum required cone shell plate thickness (inches)
$T_T$ = Total force on one foot strip (lb/ft.)
f = Allowable steel unit stress (13,700 psi) [2.1]
E = Joint efficiency factor (0.66) [11-Table 1]

The measured minimum plate thickness in the cone is 0.255"

Service Factor (SF) = $\frac{t_{actual}}{t_{required}} = \frac{0.255}{0.0678} = 3.32$ Therefore, cone shell is OK

## 5C. Calculation at Cone to Cylinder Junction

$$C = \frac{\gamma}{8}(X + \frac{D}{6}Cot\theta)D^2 Tan\theta$$ [11-Eq. 34]

C = Compressive force (lbs)
$\gamma$ = Density of contained liquid (pcf)
X = Distance from top of tank (ft.)
D = Diameter of tank (ft.)
$\theta$ = Apex angle of cone (degrees)

$$C = \frac{62.4 \times 1.33}{8}(15.0 + \frac{10.0}{6}Cot32.2°)10.0^2 Tan32.2° = 11{,}528 \text{ lb}$$

$$A_{eff} = 0.78(t_c\sqrt{(R_c t_c)} + t_1\sqrt{(R_1 t_1)})$$ [11-Eq. 35a]

$A_{eff}$ = Effective area of compression (sq. in.)
$t_c$ = Thickness of cone (inches)
$R_c$ = Radius of cone base (inches)
$t_1$ = Thickness of cylindrical shell (inches)
$R_1$ = Radius of shell (inches)

$$A_{eff} = 0.78[0.255\sqrt{(60 \times 0.255)} + 0.296\sqrt{(60 \times 0.296)}] = 1.75 \text{ sq. in.}$$

$A_{eff_{max}} = 16(t_c^2 + t_1^2) = 16(0.255^2 + 0.296^2) = 2.44$ sq. in. --- Use 1.75 sq. in. [11-Eq. 35b]

Summation of Forces at Cone to Cylinder Junction

Compression force = 11,528 lb
Combined tension force = 8,611 lb
Net Compressive force = 2,917 lb

$$\text{Compressive stress} = \frac{NCF}{A_{eff}} = \frac{2917}{1.75} = 1{,}665 \text{ psi}$$

Maximum allowable compressive stress

$$f_a = 2{,}000{,}000\frac{t}{R}(1 - \frac{100}{3}\frac{t}{R}) \qquad \text{[11-Eq. 26]}$$

$f_a$ = Allowable compressive unit stress (psi)
t = Plate thickness (in.)
R = Radius of curvature normal to direction of stress (in.)

$$f_a = 2{,}000{,}000\frac{0.255}{60}(1 - \frac{100}{3} \times \frac{0.255}{60}) = 7{,}296 \text{ psi} < 15{,}000 \text{ psi}$$

$$\text{Service Factor (SF)} = \frac{f_{allow}}{f_{actual}} = \frac{7296}{1665} = 4.38$$ Therefore, Cone to cylinder junction O.K.

**6. Calculation of Seismic Forces on the Tank**

A. Seismic Formula -- Seismic Zone #1 (Ohio) [Ohio Basic Building Code = OBBC]

$V = 2.5\ A_v\ I\ K\ C\ S\ W$ [OBBC 1113.4]

V = Lateral Seismic Force (lbs)
$A_v$ = 0.075 (Coefficient for Ohio) [OBBC 1113.4.1]
I = Importance Factor (For industrial plants, I = 1.0) [OBBC 1113.4.2]
K = Horizontal Force Factor (For a tank on legs, K = 2.5) [OBBC 1113.4.3] [& OBBC 1113.9.3]
C S = Coefficient combination (For zones 0, 1 & 2, CS = 0.14) [OBBC 1113.4.4]
W = Weight of the fully loaded tank (lbs)

$V = 2.5 \times 0.075 \times 1.0 \times 2.5 \times 0.14 \times (10{,}962 \text{ lbs} + 114{,}978 \text{ lbs}) = 8{,}265 \text{ lbs}$

B. Overturning Moment Due to Seismic Force

OTM = V /1000 × arm

OTM = Overturning Moment about base (ft. kips)
arm = Vertical Distance from the base to center of gravity of loaded tank(ft.)
arm = (15'-0") /2 + 6'-9" + 4'-8 5/8" = 18.97' (conservative distance)

OTM = 8,265 lbs/1000 lbs/kip × 18.97' = 156.8 ft. kips

C. Resisting Moment of the Tank -- Full Tank

RM = W /1000 × delta

RM = Resisting Moment (ft. kips)
delta = Horizontal Distance from the center of the tank to its overturning point (ft.)

RM = (10,962 lbs + 114,978 lbs) /1000 lbs /kip × (7.54) /2 = 474.8 ft. kips

D. Factor of Safety Against Seismic Overturning

Factor of Safety (FOS) = RM / OTM = 474.8 / 156.8 = 3.0

Since FOS is greater than 1.5, tank is safe against overturning from seismic forces.

**7. Calculation of Wind Forces on the Tank** [Ohio Basic Building Code = OBBC]

A. Wind Formula -- 80 mph wind zone -- Exposure B

$P_d = P_e \times I^2 \times C_p$ [OBBC 1112.3]

Definitions as follows: [OBBC 1112.2]

$P_d$ = Design Wind Pressure (lbs per sq. ft.)
$P_e$ = Effective Velocity Pressure - Exposure B ($P_e$ = 13psf) [OBBC Table 1112.3.3a ]
I = Importance Factor for Service (I = 1.0) [OBBC Table 1112.2a(1)]
$C_p$ = External Pressure Coefficient for Round Tanks [OBBC Table 1112.2d ]
For h/D = (15'-0"+ 6'-4") / 10'-0" = 2.13, $C_p$ = 0.8

$P_d = 13 \times (1.0)^2 \times 0.8 = 10.4$ psf

B. Wind Force on Tank

$P_1 = P_d \times$ Wind Area

Wind $\text{Area}_1$ = D × H = 10'-0" × 15'-0" = 150.0 sq. ft.
D = Tank Diameter (ft.)
H = Tank Height (ft.)

$P_1 = 10.4 \times 150.0 = 1{,}560$ lbs.

$P_2 = P_d \times$ Wind Area

Wind Area = $\dfrac{D+d}{2} \times h$ = (10'-0"+1'-6")/2 × 6'-9" = 38.8 sq. ft.

d = Cone bottom diameter (ft.)

h = Cone height (ft.)

$P_2$ = 10.4 × 38.8 = 404 lbs

C. Overturning Moment due to Wind Force

OTM = P /1000 × arm

arm = Vertical Distance from the base to center of gravity of the wind area (ft.)

$arm_1$ = (15'-0") /2 + 6'-9" + 4'-8 5/8" = 18.97 ft.

$arm_2$ = (6'-9") × 2/3 + 4'-8 5/8" = 9.21 ft.

OTM = 1,560 lbs /1000 lbs/kip × 18.97'+ 404 lb/1000 lbs/kip × 9.21' = 33.3 ft. kips

D. Resisting Moment of Tank -- Empty Tank

RM = DL / 1000 × delta

RM = Resisting Moment (ft. kips)

DL = Dead Load of Tank (Weight of empty tank) (lbs)

delta = Horizontal Distance from center of tank to its overturning point (c/c legs /2)

RM = 10,962 lbs /1000 lbs/kip × (7.54') /2 = 41.3 ft. kips

E. Factor of Safety Against Wind Overturning

Factor of Safety (FOS) = RM / OTM = 41.3 / 33.3 = 1.24

Since FOS is less than 1.5, tank requires anchorage.

F. Use of Anchor Bolts

Installation of this tank included placement of 2 - 1 inch diameter anchor bolts, embedded into the concrete foundation at each leg baseplate.

Determine the required force in each bolt to resist overturning of maximum wind.

$$F = \frac{(OTM \times FOS - RM) / d}{2legs \times 2bolts / leg}$$

F = Required force per bolt (kip)

OTM = Overturning Moment due to Maximum Wind Force (ft-kips)

FOS = Factor of Safety of 1.50

RM = Resisting Moment of Tank - Empty (ft-kips)

d = Distance between tank legs (ft.)

$$F = \frac{(33.3 \times 1.50 - 41.3) / 7.54}{2 \times 2} = 0.29 \text{ kips per bolt}$$

Allowable tension, 1" diam., A 36 steel bolt = 15.0 k [17-pg 4-3]

Anchor bolts will safely secure tank to the foundation.

**8. Frost Heave** [14.3c]

Maximum frost design depth per local Building Code in this area is 30 inches.

Assuming the underlaying soil is completely saturated with water and had frozen solid and using an expansion factor of water to ice as 10%, the frozen area would rise 30 inches x 0.10 or 3 inches above an unfrozen area.

The tanks of this dike system all set directly upon an 7 inch thick reinforced concrete slab poured over an existing 6" concrete slab-on-grade. The containment slab is 19'-0" wide x 59'-0" long.

Assuming the maximum condition where the narrow side of the slab-on-grade has 30 inches of water under it, and the other side has 30 inches of ice, the differential due to frost heave would be 3 inches vertical movement in 30'-0" horizontal distance.

A. Proportion to find differential elevation of base:

$$\frac{V}{H} = \frac{Y}{h}$$

V = Vertical movement of slab (inches)
H = Horizontal length of slab (ft.)
Y = Vertical rise of tank edge (inches)
h = Horizontal distance between tank supports,

Y = (V/H) x (h)
= (3" / 19'-0") x (7.54') = 1.1905 inch vert. rise

B. Proportion to find resulting offset of Center of Gravity of tank:

$$\frac{Y}{h} = \frac{X}{d}$$

X = Horizontal offset distance to center of tank (inches)
d = Vertical distance from base to center of tank (ft.)

X = (Y/h) x (d)
= (1.1905" / 7.54') x (15'-0"/2 + 6'-9" + 4'-8 5/8") = 2.995 in. = 0.2496 ft.

C. Calculate resulting Frost Resisting Moment:
FRM = DL x delta

FRM = Frost Resisting Moment (ft. kips)
DL = Dead Load of Tank (Weight of empty tank) (lbs)
delta = Horizontal Distance from center of tank to its overturning point (ft.)

FRM = 10,962 lbs/1000 lbs/kip x [(7.54') /2 - 0.2496] = 38.59 ft. kips

D. Overturning Moment due to Wind Force [para. 7.C.]
OTM = 33.3 ft. kips

E. Factor of Safety Against Overturning:
Factor of Safety (FOS) = FRM/OTM = 38.59/33.3 = 1.16 < 1.5

Determine the required force in each anchor bolt to resist overturning of frost and maximum wind.

**8A. Use of Anchor Bolts**

Installation of this tank included placement of 2 - 1 inch diameter anchor bolts, embedded into the concrete foundation at each leg baseplate.

Determine the required force in each bolt to resist overturning of maximum wind.

$$F = \frac{(OTM \times FOS - FRM) / d}{2legs \times 2bolts / leg}$$

F = Required force per bolt (kip)
OTM = Overturning Moment due to Maximum Wind Force (ft-kips)
FOS = Factor of Safety of 1.50
FRM = Frost Resisting Moment of Tank - Empty (ft-kips)
d = Distance between tank legs (ft.)

$$F = \frac{(33.3 \times 1.50 - 38.59) / 7.54}{2 \times 2} = 0.38 \text{ kips per bolt}$$

Allowable tension, 1" diam., A 36 steel bolt = 15.0 k [17-pg 4-3]

Anchor bolts will safely secure tank to the foundation.

Anchor bolts will safely secure tank to the foundation.

**9. Foundation Investigation** [14.3]

The bottom of the containment area is a 7" thick reinforced concrete slab, poured over an existing 6" concrete slab minimum thickness.
Tank has 4 legs, each with a loading of 31,485 lbs. and each with a 12" sq. base plate.
Area of soil bearing under a leg is $(6" + 7" + 12" + 7"\ 6")^2 = (3'\text{-}2")^2 = 10.03$ sq. ft.

| | |
|---|---|
| Each leg produces a base pressure of 31,485 / 10.03 sq. ft. = | 3,139 psf |
| The 7" and 6" base slabs produce a pressure of (7" + 6") /12") × 150 lbs/cu. ft.) | 162 psf |
| Total soil pressure under each tank leg | 3,302 psf |
| Existing soil bearing | [21] |
| Allowable soil bearing capacity | 4,000 psf |

The existing soil bearing capacity is adequate to support the tank.

**10. Containment Wall Investigation** [14.3]

A. Construction

12" wide x 16" long x 8" high concrete masonry block
Wall is 12" wide by 4'-0" maximum height
Vertical reinforcing consists of #4 bars at 8" on centers inside face, #4 bars at 16" on centers outside face
Horizontal reinforcing consists of #4 bars at 8" on centers, both faces

B. Wall Design [18]

$P = 1/2\ w\ h^2$

P = Force on wall due to the contained liquid pressure (lbs per ft. of length)
w = Weight of contained liquid (lbs / cubic ft.)
hd = Height of contained liquid (ft.)

$P = 1/2\ (62.4 \times 1.33) \times (4'\text{-}0")^2 = 663.9$ lbs / ft.

$M = P \times 1/3\ h$

M = Moment at base of wall (ft. lbs / ft.)
P = Force on wall (lbs / ft.)
h = Height of contained liquid (ft.)

$M = 663.9 \times (1/3\ (4'\text{-}0") + 7") = 1{,}272$ ft. lbs / ft /1000 lb./kip = 1.27 ft. kips / ft.

RM = $A_s$ a d [Simplified concrete beam design function -- ]
[American Concrete Institute publication -- ACI SP-3]

RM = Resisting Moment at base of wall (ft. kips / ft.)
$A_s$ = Area of reinforcing steel (sq. inches / ft.) -- (for #4 @ 8", $A_s$ = 0.30) [15]
a = Coefficient of concrete design (for 24 ksi steel and 3 ksi concrete use 1.76) [16]
d = Distance from face of wall to centerline of far reinforcing bar.

RM = 0.30 × 1.76 × (11 5/8"-3") = 4.55 ft. kips / ft.

C. Factor of Safety of Containment Wall

Factor of Safety (FOS) = RM / M = 4.55 / 1.27 = 3.6

Since FOS is greater than 1.0, therefore, the wall will safely contain the full height of 1.33 s.g. fluid.

Structural Assessment of a Hazardous Waste Storage Tank
for Hukill Chemical Company
*by S. M. Haw Associates, Inc.*
*Professional Engineers*

November 10, 1995

## 1. Description

*Hazardous Waste Dike Identification*:.....F-1 Fuels Dike System [C]
*Tank Designation*:...................................V-6000C
*Rated Capacity*:.......................................6,000 Gallons
*Specific Gravity of Contained Liquid*: .....1.33 (Maximum Use)
*Part B Application, Section D Location*: .Exhibit D-6
*Tank Construction*: .Vertical, welded carbon steel plate with cone bottom and 6 legs [1.8]
*Design Standard:* .............None
*Material Specifications*:...Shell, Assumed Minimum ASME SA 515 Grade 55 carbon steel[2.1]
Legs, Steel Angles ASTM A36
*Tank Dimensions*:.............Cyl. Shell Height: 8'-1 3/4" Shell Diameter: (Inside) 10'-6" [1.8]
Bottom Cone Height: 5'-3" Shell Thickness (Design): 1/4"
Total Height: 16'-11" Cone Thickness (Design): 1/4"
*Tank Shell Thickness Measurements:* Minimum measured shell, top: 0.238 inches [3.9]
Minimum measured shell, cone: 0.240 inches

## 2. Tank Weight

| | | |
|---|---|---|
| Cylindrical Shell Area: | $A = \pi \times d \times h$ | [4] |
| | $= 3.1416 \times (10'\text{-}6'') \times 8.17 = 269.5$ sq. ft | |
| Cylindrical Shell Weight: | Wt = A × (pl. wt.) | [8.1] |
| | = 269.5 × 10.2 lbs./sq. ft. (1/4") = | 2,749 lb |
| Top Area: | $A = \pi \times d^2/4$ | [5] |
| | $= 3.1416 \times (10'\text{-}6'')^2 / 4 = 86.6$ sq. ft. | |
| Top Weight | Wt = A × (pl. wt.) | [8.1] |
| | = 86.6 × 10.2 lbs./sq. ft. (1/4") = | 883 lb |
| Bottom Cone Slant Hgt. | $c = \sqrt{a^2 + b^2}$ | [6] |
| | $= \sqrt{(5'\text{–}3'')^2 + (5'\text{–}3'')^2} = 7.42$ ft. | |
| Bottom Cone Area: | $A = 1/2 \times \pi \times d \times s$ | [7] |
| | $= 1/2 \times \pi \times 10'\text{-}6'' \times 7.42 = 122.4$ sq. ft. | |
| Bottom Cone Weight: | Wt = A × (pl. wt.) | [8.1] |
| | = 122.4 × 10.2 lbs./sq. ft. (1/4") = | 1,248 lb |
| Legs, Weight: | 6 Angles 5 × 5 × 1/2 (16.2 plf) | [17-pg 1-47] |
| | 6 × 9'-10 1/2" × 16.2 = | 960 lb |

| | | |
|---|---|---|
| Top Angle Band, Weight: | 1 Angle 4× 4× 3/8 (9.8 plf) | [17-pg 1-48] |
| | circumference = $\pi \times d$ | [5] |
| | $= \pi \times 10.5 = 33.0$ lin. ft. × 9.8 plf= | 323 lb |
| Bot. Angle Band, Weight: | 1 Angle 3× 3× 1/4 (4.9 plf) | [17-pg 1-49] |
| | curcumference = $\pi \times 10.5 = 33.0$ lin. ft. × 4.9 plf = | 162 lb |

Weight of Miscellaneous Appurtenances: 500 lb

TOTAL WEIGHT OF TANK: 6,825

### 3. Weight of Contained Liquid

Volume of tank above cone: $V = \pi \times d^2/4 \times ht$ [4]

$= \pi \times (10'\text{-}6'')^2/4 \times 8.17 = 707$ cu. ft.

Weight of liquid above cone: Wt= Vol × 62.4 × sp. gr.

= 707 × 62.4 × 1.33 = 58,675 lb

Volume of cone: $V = 1/3 \times \pi \times d^2/4 \times hc$ [7]

$= 1/3\ \pi \times (10'\text{-}6'')^2/4 \times 5.25 = 152$ cu. ft.

Weight of liquid in cone: Wt = Vol × 62.4 × sp. gr.

= 152 × 62.4× 1.33 = 12,615 lb

Total Liquid Weight 71,290 lb

### 4 Check Tank Legs

Tank Legs: 1 angle 5 × 5 × 1/2 -- Length = 5'-3" + 3'-6" = 8'-9"
Area = 4.75 sq. in.--Radius of gyration (z axis)=0.983 in.[17-pg 1-47]

Total Weight of Tank & Liquid: 6,825 lb. + 71,290 lb. = 78,115 lb.

Load on one leg: 78,115 / 6 = 13,019 lb

Slenderness ratio: $K \times l/r_z = 1.0\ (8.75 \times 12)/0.983 = 107$ [17-pg 5-42 & 5-135]

Allowable Comp. Stress: $F_a$ (find from AISC Table) = 12.07 ksi [17-pg 3-16]

Actual Compressive Stress: $f_a = P/A = (13{,}019 / 1000) / 4.75 = 2.74$ ksi < 12.07

Conclusion: Angles are OK

**5A. Calculation of Required Tank Wall Thickness -- Cylindrical Shell**

$$t_h = \frac{2.60 \times h \times d \times g}{f \times E}$$ [11-Eq. 4]

$t_h$ = Minimum required shell plate thickness (inches)
h = Depth from top of tank (feet)
d = Diameter of Tank (feet)
g = Specific gravity of contained liquid
f = Allowable unit stress in steel (13,700 psi) [2.1]
E = Joint efficiency factor (0.66) [11-Table 1]

$$t_h = \frac{2.60 \times 8.17 \times 10.5 \times 1.33}{13{,}700 \times 0.66} = 0.0328 \text{ inches}$$

Minimum measured thickness = 0.238

Service Factor (SF) = $\dfrac{t_{actual}}{t_{required}} = \dfrac{0.238}{0.0328} = 7.25$

Conclusion: The cylindrical shell is OK

**5B. Calculation of Required Tank Wall Thickness -- Cone**

Hoop Force at Spring Line

$$T_1 = \frac{\lambda \times D \times X}{2\text{Cos}\theta}$$ [11-Eq. 33]

$T_1$ = Total Force (lbs/ft.)
$\gamma$ = Desity of contained liquid (lbs/cu.ft.)
D = Tank diameter (feet)
X = Distance from top of tank (feet)
$\theta$ = Apex angle (degrees) = $\tan^{-1}\dfrac{D/2}{h_c} = \tan^{-1}\dfrac{(10'-6")/2}{5'-3"} \therefore \theta = 45°$ [6]

$$T_1 = \frac{(62.4 \times 1.33) \times 10.5 \times 8.17}{2\text{Cos}45°} = 5{,}034 \text{ lb/ft.}$$

Longitudinal Force at Spring Line

$$T_2 = \frac{\gamma}{2Cos\theta} \times \frac{D}{2} \times (X + \frac{D}{6} \times Cot\theta)$$ [11-Eq. 32]

$T_2$ = Total Force (lb/ft.)
$\gamma$ = Density of liquid (pcf)
D = Tank Diameter (feet)
X = Distance to tope of tank (feet)
$\theta$ = Apex angle (degrees)
hc = Height of Cone

$$T_2 = \frac{(62.4 \times 1.33)}{2Cos45°} \times \frac{10.5}{2} \times (8.17 + \frac{10.5}{6} \times Cot45°) = 3{,}056 \text{ lb/ft.} < 5{,}034 \text{ lb/ft.}$$

$$t_h = \frac{T_T}{f \times E} = \frac{5{,}034/12}{13700 \times 0.66} = 0.0464 \text{ inches}$$ [11-Eq. 4]

$t_h$= Minimum required cone shell plate thickness (inches)
$T_T$ = Total force on one foot strip (lb/ft.)
f = Allowable steel unit stress (13,700 psi) [2.1]
E = Joint efficiency factor (0.66) [11-Table 1]

The measured minimum plate thickness in the cone is 0.238"

The service factor (SF) is $\frac{t_{actual}}{t_{required}} = \frac{0.238}{0.0464} = 5.13$ Therefore, cone is OK

## 5C. Calculation at Cone to Cylinder Junction

$$C = \frac{\gamma}{8}(X + \frac{D}{6}Cot\theta)D^2 Tan\theta$$ [11-Eq. 34]

C = Compressive force (lbs)
$\gamma$ = Density of contained liquid (pcf)
X = Distance from top of tank (ft.)
D = Diameter of tank (ft.)
$\theta$ = Apex angle of cone (degrees)

$$C = \frac{62.4 \times 1.33}{8}(8.17 + \frac{10.5}{6}Cot45°)10.5^2 Tan45° = 11{,}346 \text{ lb}$$

$A_{eff} = 0.78(t_c\sqrt{(R_c t_c)} + t_1\sqrt{(R_1 t_1)})$ [11-Eq. 35a]

$A_{eff}$ = Effective area of compression (sq. in.)
$t_c$ = Thickness of cone (inches)
$R_c$ = Radius of cone base (inches)
$t_1$ = Thickness of cylindrical shell (inches)
$R_1$ = Radius of shell (inches)

$A_{eff} = 0.78[0.240\sqrt{(63 \times 0.240)} + 0.238\sqrt{(63 \times 0.238)}] = 1.45$ sq. in.

$A_{eff_{max}} = 16(t_c^2 + t_1^2) = 16(0.240^2 + 0.238^2) = 1.83$ --- Use 1.45

Summation of Forces at Cone to Cylinder Junction

Compression force = 11,346 lb
Combined tension force = 6,055 lb
Net Compressive force = 5,291 lb

Compressive stress = $\dfrac{NCF}{A_{eff}} = \dfrac{5{,}291}{1.45} = 3{,}649$ psi

Maximum allowable compressive stress

$f_a = 2{,}000{,}000\dfrac{t}{R}(1 - \dfrac{100}{3}\dfrac{t}{R})$ [11-Eq. 26]

$f_a$ = Allowable compressive unit stress (psi)
t = Plate thickness (in.)
R = Radius of curvature normal to direction of stress (in.)

$f_a = 2{,}000{,}000\dfrac{0.240}{63}(1 - \dfrac{100}{3} \times \dfrac{0.240}{63}) = 6{,}652 \text{ psi} < 15{,}000 \text{ psi}$

Service Factor (SF) = $\dfrac{f_{allow}}{f_{actual}} = \dfrac{6652}{3649} = 1.82$ Therefore, cone to cylinder junction O.K.

**6. Calculation of Seismic Forces on the Tank**

A. Seismic Formula -- Seismic Zone #1 (Ohio) [Ohio Basic Building Code = OBBC]

$V = 2.5\ A_v\ I\ K\ C\ S\ W$ [OBBC 1113.4]

V = Lateral Seismic Force (lbs)
$A_v$ = 0.075 (Coefficient for Ohio) [OBBC 1113.4.1]
I = Importance Factor (For industrial plants, I = 1.0) [OBBC 1113.4.2]
K = Horizontal Force Factor (For a tank on legs, K = 2.5) [OBBC 1113.4.3] [& OBBC 1113.9.3]
C S = Coefficient combination (For zones 0, 1 & 2, CS = 0.14) [OBBC 1113.4.4]
W = Weight of the fully loaded tank (lbs)

V = 2.5 × 0.075 × 1.0 × 2.5 × 0.14 × (6,825 lbs + 71,290 lbs) =5,126 lbs

B. Overturning Moment Due to Seismic Force

OTM = V /1000 × arm
OTM = Overturning Moment about base (ft. kips)
arm = Vertical Distance from the base to center of gravity of loaded tank(ft.)
= (8'-2") /2 + 5'-3" + 3'-6" = 12.83' (conservative distance)

OTM = 5,126 lbs/1000 lbs/kip × 12.83' = 65.8 ft. kips

C. Resisting Moment of the Tank -- Full Tank

RM = W /1000 × delta
RM = Resisting Moment (ft. kips)
delta = Horizontal Distance from the center of the tank to its overturning point (ft.)
= 2 × (10'-6") /2 (Sin 60°) = 2(4.55) = 9.10 ft.

RM = (6,825 lbs + 71,290 lbs) /1000 lbs /kip × (9'-10") /2 = 384.1 ft. kips

D. Factor of Safety Against Seismic Overturning

Factor of Safety (FOS) = RM / OTM = 381.4 / 65.8 = 5.80
Since FOS is greater than 1.5, tank is safe against overturning from seismic forces.

**7. Calculation of Wind Forces on the Tank** [Ohio Basic Building Code = OBBC]

A. Wind Formula -- 80 mph wind zone -- Exposure B

$P_d = P_e \times I^2 \times C_p$ [OBBC 1112.3]

Definitions as follows: [OBBC 1112.2]

$P_d$ = Design Wind Pressure (lbs per sq. ft.)

$P_e$ = Effective Velocity Pressure - Exposure B ($P_e$ = 13psf) [OBBC Table 1112.3.3a ]

I = Importance Factor for Service (I = 1.0) [OBBC Table 1112.2a(1)]

$C_p$ = External Pressure Coefficient for Round Tanks [OBBC Table 1112.2d ]

For h/D = 8'-2"+ 5'-3" / 10'-6" = 1.28, $C_p$ = 0.8

$P_d = 13 \times (1.0)^2 \times 0.8 = 10.4$ psf

B. Wind Force on Tank

$P_1 = P_d \times$ Wind Area

Wind $\text{Area}_1 = D \times H$ = 10'-6" × 8'-2" = 85.8 sq. ft.

D = Tank Diameter (ft.)

H = Tank Height (ft.)

$P_1 = 10.4 \times 85.8 = 892$ lbs.

$P_2$ = Pd × Wind Area

Wind Area = $\frac{D+d}{2} \times h$ = (10'-6" + 0)/2 × 5'-3" = 27.6 sq. ft.

d = Cone bottom diameter

h = Cone height

$P_2 = 10.4 \times 27.6 = 287$ lbs

C. Overturning Moment due to Wind Force

OTM = P /1000 × arm

arm = Vertical Distance from the base to center of gravity of the wind area (ft.)

$\text{arm}_1$ = (8'-2") /2 + 5'-3" + 3'-6" = 12.83 ft.

$\text{arm}_2$ = (5'-3") × 2/3 + 3'-6" = 7.00 ft.

OTM = 892 lbs /1000 lbs/kip × 12.83'+ 287 lb/1000 lbs/kip × 7.00' = 13.5 ft. kips

D. Resisting Moment of Tank -- Empty Tank

RM = DL / 1000 × delta

RM = Resisting Moment (ft. kips)

DL = Dead Load of Tank (Weight of empty tank) (lbs)

delta = Horizontal Distance from center of tank to its overturning point (c/c legs /2)

= 2 × (10'-6") /2 (Sin 60°) = 2(4.55) = 9.10 ft.

RM = 6,825 lbs /1000 lbs/kip × (9.10') /2 = 31.0 ft. kips

E. Factor of Safety Against Wind Overturning
Factor of Safety (FOS) = RM / OTM = 31.0 / 13.5 = 2.30
Since FOS is greater than 1.5, therefore, tank is safe against overturning from wind forces.

**8. Frost Heave** [14.3c]
Maximum frost design depth per local Building Code in this area is 30 inches.

Assuming the underlaying soil is completely saturated with water and had frozen solid and using an expansion factor of water to ice as 10%, the frozen area would rise 30 inches x 0.10 or 3 inches above an unfrozen area.

The tanks of this dike system all set directly upon an 7 inch thick reinforced concrete slab poured over an existing 6" concrete slab-on-grade. The containment slab is 19'-0" wide x 59'-0" long

Assuming the maximum condition where the narrow side of the slab-on-grade has 30 inches of water under it, and the other side has 30 inches of ice, the differential due to frost heave would be 3 inches vertical movement in 30'-0" horizontal distance.

A. Proportion to find differential elevation of base:

$$\frac{V}{H} = \frac{Y}{h}$$

V = Vertical movement of slab (inches)
H = Horizontal length of slab (ft.)
Y = Vertical rise of tank edge (inches)
h = Horizontal distance between tank supports

Y = (V/H) x (h)
= (3" / 19'-0") x (9.10') = 1.4368 inch vert. rise

B. Proportion to find resulting offset of Center of Gravity of tank:

$$\frac{Y}{h} = \frac{X}{d}$$

X = Horizontal offset distance to center of tank (inches)
d = Vertical distance from base to center of tank (ft.)

X = (Y/h) x (d)
= (1.4368" / 9.10') x (8'-1")/2 +5'-3" + 3'-6" = 2.0197 in. = 0.1683 ft.

C. Calculate resulting Frost Resisting Moment:

FRM = DL x delta

FRM = Frost Resisting Moment (ft. kips)
DL = Dead Load of Tank (Weight of empty tank) (lbs)
delta = Horizontal Distance from center of tank to its overturning point (ft.)

FRM = 6,825 lbs/1000 lbs/kip x [(9.10') /2 - 0.1683] = 29.91 ft. kips

D. Overturning Moment due to Wind Force [para. 7.C.]

OTM = 13.5 ft. kips

E. Factor of Safety Against Overturning:

Factor of Safety (FOS) = FRM/OTM = 29.91/13.5 = 2.22 > 1.5
OK

**9. Foundation Investigation** [14.3]

The bottom of the containment area is a 7" thick reinforced concrete slab, poured over and existing 6" concrete slab minimum thickness.
Tank has 6 legs, each with a loading of 13,019 lbs. and each with a 8" x 12" sq. base plate.
Area of soil bearing under a leg is (6" + 7" + 12" + 7" + 6") × (6" + 7" + 8" 7" + 6") = 38" × 34" = 8.97 sq. ft.

| | |
|---|---|
| Each leg produces a base pressure of 13,019 / 8.97 sq. ft. = | 1,451 psf |
| The 7" and 6" base slabs produce a pressure of (7" + 6")/12" × 150 lbs/cu. ft.) | 162 psf |
| Total soil pressure under each tank leg | 1,613 psf |

Existing soil bearing [21]

Allowable soil bearing capacity 4,000 psf

The concrete base slab and the soil capacity is adequate to carry the tanks

**10. Containment Wall Investigation** [14.3]

A. Construction

12" wide x 16" long x 8" high "Ivany" concrete masonry block
Wall is 12" wide by 4'-0" maximum height
Vertical reinforcing consists of #4 bars at 8" on centers inside face, #4 bars at 16" on centers outside face
Horizontal reinforcing consists of #4 bars at 8" on centers, both faces

B. Wall Design [18]

$P = 1/2\ w\ h^2$

P = Force on wall due to the contained liquid pressure (lbs per ft. of length)
w = Weight of contained liquid (lbs / cubic ft.)
hd = Height of contained liquid (ft.)

P = 1/2 (62.4 × 1.33) × (4'-0")$^2$ = 663.9 lbs / ft.

M = 1/3 P h

M = Moment at base of wall (ft. lbs / ft.)
P = Force on wall (lbs / ft.)
h = Height of contained liquid (ft.)

M = 1/3× 663.9 (4'-0" +7" = 1,272 ft. lbs / ft/ft./1000 lb./kip = 1.27 ft. kips / ft.

RM = $A_s$ a d

[Simplified concrete beam design function -- ]
[American Concrete Institute publication -- ACI SP-3]

RM = Resisting Moment at base of wall (ft. kips/ ft.)
$A_s$ = Area of reinforcing steel (sq. inches / ft.) -- (for #4 @ 8", $A_s$ = 0.30) [15]
a = Coefficient of concrete design (for 24 ksi steel and 3 ksi concrete use 1.76) [16]
d = Distance from face of wall to centerline of far reinforcing bar.

RM = 0.30 × 1.76 × (11 5/8" - 3") = 4.55 ft. kips / ft.

C. Factor of Safety of Containment Wall

Factor of Safety (FOS) = RM / M = 4.55 / 1.27 = 3.6

Since FOS is greater than 1.0, therefore, the wall will safely contain the full height of 1.33 s.g. fluid.

Structural Assessment of a Hazardous Waste Storage Tank
for Hukill Chemical Company

*by S. M. Haw Associates, Inc.*

*Professional Engineers*

November 10, 1995

**1. Description** [C]

*Hazardous Waste Dike Identification*: .....F-1 Fuels Dike System
*Tank Designation*: ..................................13-15M
*Rated Capacity*: .......................................15,000 Gallons
*Specific Gravity of Contained Liquid*: .....1.33 (Maximum Use)
*Part B Application, Section D Location*: .Exhibit D-6
*Tank Construction*: .Vertical, welded carbon steel plate with flat cone bottom and 4 legs setting on 4 concrete piers [1.9a]
*Design Standard:* ............None
*Material Specifications*: ...Shell, Assumed Minimum ASME SA 515 Grade 55 carbon steel [2.1]
Legs, Steel Beams ASTM A36
*Tank Dimensions*: .............Cyl. Shell Height: 27'-0" Shell Diameter: 10'-0" (I.D.) [1.9b]
Bottom Cone Height: 7" Shell Thickness, top (Design): 1/4"
Total Height: 32'-1 Shell Thickness, bottom (Design): 3/8"
Cone Thickness (Design): 3/8"
*Tank Shell Thickness Measurements:* Minimum measured shell, top: 0.249 inches [3.3]
Minimum measured shell, upper: 0.248 inches
Minimum measured shell, middle: 0.247 inches
Minimum measured shell, lower: 0.246 inches
Minimum measured shell, bottom: 0.379 inches

**2. Weight of Tank**

| | | |
|---|---|---|
| Cylindrical Upper Shell Area: | $A = \pi \times d \times h$ | [4] |
| | $= 3.1416 \times 10'\text{-}0" \times 21'\text{-}0" = 659.7$ sq. ft | |
| Cylindrical Upper Shell Weight: | $Wt = A \times$ (pl. wt.) | [8.1] |
| | $= 659.7 \times 10.2$ lbs./sq ft. (1/4") = | 6,729 lb |
| Cylindrical Lower Shell Area: | $A = \pi \times d \times h$ | [4] |
| | $= 3.1416 \times 10'\text{-}0" \times 6'\text{-}0" = 188.5$ sq. ft | |
| Cylindrical Lower Shell Weight: | $Wt = A \times$ (pl. wt.) | [8.1] |
| | $= 188.5 \times 15.3$ lbs./sq. ft. (3/8") = | 2,884 lb |
| Top Area: | $A = \pi \times d^2/4$ | [5] |
| | $= 3.1416 \times (10'\text{-}0")^2/4 = 78.5$ sq. ft. | |
| Top Weight: | $Wt = A \times$ (pl. wt.) | [8.1] |
| | $= 78.5 \times 10.2$ lbs./sq. ft. (1/4") = | 801 lb |

Structural Assessment of a Hazardous Waste Storage Tank
for Hukill Chemical Company
F-1 Fuels Dike System -- Tank 13-15M

| | | | |
|---|---|---|---|
| Bottom Cone Slant Hgt.: | $c = \sqrt{a^2 + b^2}$ | [6] | |
| | $= \sqrt{(7")^2 + (5'-0")^2} = 5.03$ ft. | | |
| Bottom Cone Area: | $A = 1/2 \times \pi \times d \times s$ | [7] | |
| | $= 1/2 \times \pi \times 10'\text{-}0" \times 5.03 = 79.0$ sq. ft. | | |
| Bottom Cone Weight: | Wt = A × (pl. wt.) | [8.1] | |
| | = 79.0 × 15.3 lbs./sq. ft. (3/8") = | | 1,209 lb |
| Legs, Weight: | 4 Beams - W8 x 35 (35 plf) × 6'-6" = 26'-0" ft. × 35 = | | 910 lb |
| Weight of Agitator: | | | 3,700 lb |
| Weight of Miscellaneous Appurtenances: | | | 500 lb |
| TOTAL WEIGHT OF TANK: | | | 16,733 lb |

**3. Weight of Contained Liquid**

| | | | |
|---|---|---|---|
| Volume of tank above cone: | $V = \pi \times d^2/4 \times ht$ | [4] | |
| | $= \pi \times (10'-0")^2/4 \times 27'\text{-}0" = 2{,}121$ cu. ft. | | |
| Weight of liquid above cone: | Wgt = Vol × 62.4 × sp. gr. | | |
| | = 2,121 × 62.4 × 1.33 = | | 176,026 lb |
| Volume of cone: | $V = 1/3 \times \pi \times d^2/4 \times hc$ | [7] | |
| | $= 1/3 \times \pi \times (10'-0")^2/4 \times 0.58' = 15$ cu. ft. | | |
| Weight of liquid in cone: | Wgt = Vol × 62.4 × sp. gr. | | |
| | = 15 × 62.4 × 1.33 = | | 1,245 lb |
| Total Liquid Weight: | | | 177,271 lb |

**4. Check Tank Legs**

| | | | |
|---|---|---|---|
| Tank Legs: | Beam - W8 x 35 -- Length = 1'-1" | | |
| | Area = 10.3 sq. in. -- Radius of gyration (y axis) = 2.03 in. | [17-pg 1-32] | |
| Total Weight of Tank & Liquid: | 16,733 lb. + 177,271 lb. = | | 194,004 lb |
| Load on one leg: | 194,004 lb. / 4 = | | 48,501 lb |
| Slenderness ratio: | $K \times l/r_y = 2.0\ (1.08 \times 12)/2.03 = 13$ | | |

Allowable Comp. Stress: $F_a$ (find from AISC Table 3-36) = 21.00 ksi [17-pg 3-16]
Actual Compressive Stress: $f_a = P/A = (48{,}501 / 1000) / 10.3 = 4.70$ ksi < 21.00
Conclusion: Legs are OK

**5A. Calculation of Required Tank Wall Thickness -- Cylindrical Shell**

$$t_h = \frac{2.60 \times h \times d \times g}{f \times E}$$ [11-Eq. 4]

$t_h$ = Minimum required shell plate thickness (inches)
h = Depth from top of tank (feet)
d = Diameter of tank (ft.)
g = Specific gravity of contained liquid
f = Allowable unit stress (13,700 psi) [2.1]
E = Joint efficiency factor (0.66) [11-Table 1]

At h = 21'-0" from top of tank

$$t_h = \frac{2.60 \times 21'\text{-}0'' \times 10'\text{-}0'' \times 1.33}{13{,}700 \times 0.66} = 0.0803 \text{ inches}$$

Minimum measured thickness = 0.246 inches @ 21'-0 from top

$$\text{Service Factor (SF)} = \frac{t_{actual}}{t_{required}} = \frac{0.246}{0.0803} = 3.06$$

Conclusion: The upper cylindrical shell is OK

At h = 27'-0" from top of tank

$$t_h = \frac{2.60 \times 27'\text{-}0'' \times 10'\text{-}0'' \times 1.33}{13{,}700 \times 0.66} = 0.1033 \text{ inches @ 27'-0'' from top}$$

Minimum measured thickness = 0.379 inches

$$\text{Service Factor (SF)} = \frac{t_{actual}}{t_{required}} = \frac{0.379}{0.1033} = 3.67$$

Conclusion: The cylindrical shell is OK

**5B. Calculation of Required Wall Thickness-Flat Cone**

Longitudinal (Meridional) Stress atSpring Line

$$\sigma_1 = \frac{qR}{2t\cos\alpha}$$ [23-pg 449]

Hoop (Circumferential) Stress at Spring Line

$$\sigma_2 = \frac{qR}{t\cos\alpha}$$ [23-pg 449]

Using hoop stress as maximum, calculate minimum ±

$$t_h = \frac{qR}{\sigma_2 \cos\alpha}$$

$t_h$ = Minimum required cone plate thickness (inches)
q = Internal pressure (psi)
= (Weight of liquid)(height)
R = Maximum radius of cone (inches)
$\sigma_2$ = (f)(e)
f = Allowable unit stress (psi) [2.1]
e = Joint efficiency factor (0.66) [11-Table 1]
$\alpha$ = Cone apex angle (degrees)
$\tan^{-1}$ = R/hc = $\tan^{-1}$(10'-0 1/2" / 2) / 7" = 83.35 degrees
hc = Height of cone (inches)

$$t_h = \frac{(62.4 \times 1.33 \times 27'\!-\!0")/(144) \times (10'\!-\!0"/2 \times 12)}{(13{,}700)(0.66)(\cos 83.35)} = 0.8917 \text{ inches}$$

Design Cone Thickness: 3/8" [3.11]

$$\text{Service Factor (SF)} = \frac{t_{actual}}{t_{required}} = \frac{0.375}{0.8917} = 0.42$$

Conclusion: Service Factor (SF) of flat cone bottom is below the value of one (1.00). Since this tank is currently in service with no apparent structural deficiency, we recommend continuation of present usage with Hukill Chemical to monitor this area for future indication of distress.

**6. Calculation of Seismic Forces on the Tank**

A. Seismic Formula -- Seismic Zone #1 (Ohio) [Ohio Basic Building Code = OBBC]

$V = 2.5\ A_v\ I\ K\ C\ S\ W$ [OBBC 1113.4]

V = Lateral Seismic Force (lbs)
$A_v$ = 0.075 (Coefficient for Ohio) [OBBC 1113.4.1]
I = Importance Factor (For industrial plants, I = 1.0) [OBBC 1113.4.2]
K = Horizontal Force Factor (For a tank on legs, K = 2.5) [OBBC 1113.4.3] [& OBBC 1113.9.3]
C S = Coefficient combination (For zones 0, 1 & 2, CS = 0.14) [OBBC 1113.4.4]
W = Weight of the fully loaded tank (lbs)

V = 2.5 × 0.075 × 1.0 × 2.5 × 0.14 × (16,733 lbs + 117,271 lbs) =8,794 lbs

B. Overturning Moment Due to Seismic Force

OTM = V /1000 × arm
OTM = Overturning Moment about base (ft. kips)
arm = Vertical Distance from the base to center of gravity of loaded tank(ft.)
arm = (27'-0") /2 + 5'-1" = 18.58'

OTM = 8,794 lbs/1000 lbs/kip × 18.58' = 163.4 ft. kips

C. Resisting Moment of the Tank -- Full Tank

RM = W /1000 × delta
RM = Resisting Moment (ft. kips)
delta = Horizontal Distance from the center of the tank to its overturning point (ft.)

RM = (16,733 lbs + 117,271 lbs) /1000 lbs /kip × (7.54) /2 = 505.2 ft. kips

D. Factor of Safety Against Seismic Overturning

Factor of Safety (FOS) = RM / OTM = 505.2 / 163.4 = 3.1
Since FOS is greater than 1.5, tank is safe against overturning from seismic forces.

**7. Calculation of Wind Forces on the Tank** [Ohio Basic Building Code = OBBC]

A. Wind Formula -- 80 mph wind zone -- Exposure B

$P_d = P_e \times I^2 \times C_p$ [OBBC 1112.3]

Definitions as follows: [OBBC 1112.2]

$P_d$ = Design Wind Pressure (lbs per sq. ft.)

$P_e$ = Effective Velocity Pressure - Exposure B ($P_e$ = 13psf) [OBBC Table 1112.3.3a ]

I = Importance Factor for Service (I = 1.0) [OBBC Table 1112.2a(1)]

$C_p$ = External Pressure Coefficient for Round Tanks [OBBC Table 1112.2d ]

For h/D = 27'-0" / 10'-0" = 2.70, $C_p$ = 0.8

$P_d = 13 \times (1.0)^2 \times 0.8 = 10.4$ psf

B. Wind Force on Tank

$P = P_d \times$ Wind Area

Wind Area = D × h = 10'-0" × 27'-0" = 270.0 sq. ft.

D = Tank Diameter (ft.)

h = Tank Height (ft.)

P = 10.4 × 270.0 = 2,808 lbs.

C. Overturning Moment due to Wind Force

OTM = P /1000 × arm

arm = Vertical Distance from the base to center of gravity of the wind area (ft.)

arm = (27'-0") /2 + 5'-1"= 18.58

OTM = 2,808 lbs /1000 lbs/kip × 18.58 = 52.2 ft. kips

D. Resisting Moment of Tank -- Empty Tank

RM = DL / 1000 × delta

RM = Resisting Moment (ft. kips)

DL = Dead Load of Tank (Weight of empty tank) (lbs)

delta = Horizontal Distance from center of tank to its overturning point (c/c legs /2)

RM = 16,733 lbs /1000 lbs/kip × (7.54) /2 = 63.1 ft. kips

E. Factor of Safety Against Wind Overturning

Factor of Safety (FOS) = RM / OTM = 63.1 / 52.2 = 1.2

Since FOS is less than 1.5, tank requires anchorage into base slab.

F. Use of Anchor Bolts
Installation of this tank included placement of 2 - 3/4 inch diameter anchor bolts, embedded into the concrete foundation at each leg baseplate.

Determine the required force in each bolt to resist overturning of maximum wind.

$$F = \frac{(OTM \times FOS - RM) / d}{2legs \times 2bolts / leg}$$

F = Required force per bolt (kip)
OTM = Overturning Moment due to Maximum Wind Force (ft-kips)
FOS = Factor of Safety of 1.50
RM = Frost Resisting Moment of Tank - Empty (ft-kips)
d = Distance between tank legs (ft.)

$$F = \frac{(52.2 \times 1.50 - 63.1) / 7.54}{2 \times 2} = 0.50 \text{ kips per bolt}$$

Allowable tension, 3/4" diam., A 36 steel bolt = 8.4 k [17-pg 4-3]

Anchor bolts will safely secure tank to the foundation.

**8. Frost Heave** [14.3c]
Maximum frost design depth per local Building Code in this area is 30 inches.

Assuming the underlaying soil is completely saturated with water and had frozen solid and using an expansion factor of water to ice as 10%, the frozen area would rise 30 inches x 0.10 or 3 inches above an unfrozen area.

The tanks of this dike system all set directly upon an 7 inch thick reinforced concrete slab poured over an existing 6" concrete slab-on-grade. The containment slab is 19'-0" wide x 59'-0" long

Assuming the maximum condition where the narrow side of the slab-on-grade has 30 inches of water under it, and the other side has 30 inches of ice, the differential due to frost heave would be 3 inches vertical movement in 30'-0" horizontal distance.

## Structural Assessment of a Hazardous Waste Storage Tank
## for Hukill Chemical Company
### F-1 Fuels Dike System -- Tank 13-15M

A. Proportion to find differential elevation of base:

$$\frac{V}{H} = \frac{Y}{h}$$

V = Vertical movement of slab (inches)
H = Horizontal length of slab (ft.)
Y = Vertical rise of tank edge (inches)
h = Horizontal distance between tank supports

Y = (V/H) x (h)
= (3" / 19'-0") x (7.54') = 1.1905 inch vert. rise

B. Proportion to find resulting offset of Center of Gravity of tank:

$$\frac{Y}{h} = \frac{X}{d}$$

X = Horizontal offset distance to center of tank (inches)
d = Vertical distance from base to center of tank (ft.)

X = (Y/h) x (d)
= (1.1905" / 7.54') x (27'-0")/2 + 7" + 4'-6" = 2.9342 in. = 0.2445 ft.

C. Calculate resulting Frost Resisting Moment:
FRM = DL x delta

FRM = Frost Resisting Moment (ft. kips)
DL = Dead Load of Tank (Weight of empty tank) (lbs)
delta = Horizontal Distance from center of tank to its overturning point (ft.)

FRM = 16,733 lbs/1000 lbs/kip x [(7.54') /2 - 0.24] = 59.07 ft. kips

D. Overturning Moment due to Wind Force [para. 7.C.]
OTM = 52.2 ft. kips

E. Factor of Safety Against Overturning:
Factor of Safety (FOS) = FRM/OTM = 59.07/52.2 = 1.13 < 1.5

Determine the required force in each anchor bolt to resist overturning of frost with maximum wind.

**8A. Use of Anchor Bolts**

Installation of this tank included placement of 2 - 3/4 inch diameter anchor bolts, embedded into the concrete foundation at each leg baseplate.

Determine the required force in each bolt to resist overturning of maximum wind.

$$F = \frac{(OTM \times FOS - FRM) / d}{2legs \times 2bolts / leg}$$

F = Required force per bolt (kip)
OTM = Overturning Moment due to Maximum Wind Force (ft-kips)
FOS = Factor of Safety of 1.50
FRM = Frost Resisting Moment of Tank - Empty (ft-kips)
d = Distance between tank legs (ft.)

$$F = \frac{(52.2 \times 1.50 - 59.1) / 7.54}{2 \times 2} = 0.64 \text{ kips per bolt}$$

Allowable tension, 3/4" diam., A 36 steel bolt = 8.4 k [17-pg 4-3]

Anchor bolts will safely secure tank to the foundation.

**9. Foundation Investigation** [14.3b]

The bottom of the containment area is a 7" thick reinforced concrete slab poured over an existing 6" concrete slab.

Tank has 4 legs, each with a loading of 48,501 lbs. and each with a 12" sq. base plate bearing on a 2'-0" diameter by 4'-0" high concrete pier.

Weight of each pier = Area of Pier × Wt. Conc. = $\pi \times d^2 / 4 \times h \times 150 lb / cu. ft.$

Wt = 3.1416 × (2'-0")$^2$ / 4 × 4'-0" × 150 = 1,885 lbs.

Area of soil bearing under each leg is: A = $\pi \times d^2 / 4$

d = (2'-0") + 7" + 6" + 6" + 7" = 4'-2"

A = $\pi$ × (4'-2")$^2$ / 4 = 13.64 sq. ft.

| | |
|---|---|
| Each leg produces a base pressure of 48,501 lb +1,885 lb. / 13.64 sq. ft. = | 3,694 psf |
| The 7" and 6" base slabs produce a pressure of (7" + 6" /12" × 150 lbs/cu. ft.) | 163 psf |
| Total soil pressure under each tank leg | 3,857 psf |

Existing soil bearing [21]

Allowable soil bearing capacity 4,000 psf

The concrete base slab and the soil capacity is adequate to carry the tank.

## 10. Containment Wall Investigation

A. Construction [14.3a]

12" wide x 16" long x 8" high "Ivany" concrete masonry block
Wall is 12" wide by 4'-0" maximum height
Vertical reinforcing consists of #4 bars at 8" on centers inside face, #4 bars at 16" on centers outside face
Horizontal reinforcing consists of #4 bars at 8" on centers, both faces

B. Wall Design [18]

$P = 1/2 \text{ w } h^2$

P = Force on wall due to the contained liquid pressure (lbs per ft. of length)
w = Weight of contained liquid (lbs / cubic ft.)
h = Height of contained liquid (ft.)

$P = 1/2\ (62.4 \times 1.33) \times (4'\text{-}0")^2 = 663.9$ lbs / ft.

$M = P \times 1/3 \text{ h}$

M = Moment at base of wall (ft. lbs / ft.)
P = Force on wall (lbs / ft.)
h = Height of contained liquid (ft.)

$M = 663.9 \times 1/3 \times (4'\text{-}0") + 7" = 1{,}272$ ft. lbs / ft / 1000 lbs / kip = 1.27 ft. kips / ft.

$RM = A_s \text{ a d}$ [Simplified concrete beam design function -- ]
[American Concrete Institute publication -- ACI SP-3]

RM = Resisting Moment at base of wall (ft. lbs / ft.)
$A_s$ = Area of reinforcing steel (sq. inches / ft.) -- (for #4 @ 8", $A_s = 0.30$) [15]
a = Coefficient of concrete design (for 24 ksi steel and 3 ksi concrete use 1.76) [16]
d = Distance from face of wall to centerline of far reinforcing bar.

$RM = 0.30 \times 1.76 \times (11\ 5/8" - 3") = 4.55$ ft. kips / ft.

C. Factor of Safety of Containment Wall

Factor of Safety (FOS) = RM / M = 4.55 / 1.27 = 3.6
Since FOS is greater than 1.0, wall will safely contain the full height of 1.33 s.g. fluid.

## 11. Design of 2'-0" Diameter Concrete Piers [14.3b]

P = Load per pier = Total weight of tank & liquid / number of legs.

$$= \text{Load per pier} = \frac{16{,}733 + 177{,}271}{4} = 48{,}501 \text{ lbs.}$$

A = Area of pier = $\pi \times d^2 / 4$ [4]
= $\pi \times (2'\text{-}0")^2 / 4 = 3.14$ sq. ft.
Axial stress in pier
f = P/A
= 48,501/3.14 = 15,446 lb./sq. ft./144 = 107 lb./sq. in.

Allowable compressive strength of 3000 psi concrete 1350 > 107 ∴ OK [16]

Addition of Seismic / wind forces to piers
Horizontal Seismic = 8,794 lbs. (USE)
Horizontal Wind = 2,808 lbs.

Horizontal Force at top of pier (Seismic)
V = 8,794 lb./4 legs = 2,199 lb.

Moment at Base of Pier
M = V × h = 2,199 lb. × 4'-0" ft. = 8,796/1,000 lb./kip = 8.80 ft. kips

Required Area of Reinforcing Steel [Simplified Beam Design Function]
$A_s$ = M/ad [American Concrete Institute Publication-ACI SP-3]
$A_s$ = Area of Reinforcing Steel (sq. in.)
M = Moment applied to pier (ft.-kip)
a = Coefficient of concrete design (for 24 ksi steel and 3 ksi concrete use 1.76) [16]
d = distance from face of pier to centerline of far reinforcing bar (inches)

$A_s$ = 8.78/1.76 × (24'-3") = 0.24 sq. inches
#4 rebar = 0.20 sq. inches [15]

Because horizontal force is due to seismic conditions, increase allowable stress in rebar by 1/3 ∴ 0.20 sq. in. × 1.33 = 0.27 sq. in. > 0.124 [ACI 318]
∴ 1- #4 rebar required for moment

Minimum area of reinforcing required by Code [ACI 318]
$A_s$ = 0.5% of gross area
$A_s = 0.005 \times \pi\ 24^2/4 = 2.26$ sq. in.
Using 8 rebars - 2.26/8 = 0.280"/bal.
Using 8 #5 rebars (0.31 sq. in.) [15]
$A_s$ = 8(0.31) = 2.48 sq. in. > 2.26 ∴ OK
use 8 - #5 rebar

# APPENDIX B

# SECONDARY CONTAINMENT CALCULATIONS

## SECONDARY CONTAINMENT CALCULATIONS

**F-1 DIKE SYSTEM** containing permitted hazardous waste storage tanks V-110M, V-210M and V-6000C and the less-than-90-day generator tank, V-115.

The largest tank in this dike has a 15,000 gallon capacity. Containment calculations will be for the 15,000 gallons and four inches of rain, the 25-year, 24-hour rainfall event for this area.

Please refer to the 8 1/2" x 11" drawing titled "F-1 DIKE SYSTEM" on the following page for dimensions used for these calculations.

Total containment of the dike is determined by obtaining the area of the rectangular containment dike and multiplying it by the lowest slab-to-top-of-wall height, 38 inches (3.167 feet).

The containment area is 54' x 17' = **918 sq.ft.**

The gross containment volume is 918 sq.ft x 3.167 ft. = **2,907.3 cu.ft. Gross Containment Volume**.

All tank cones are above the top of the wall. However, there are 4 concrete columns supporting the V-115 tank which are 4 feet high. These columns are 2 ft. diameter. The displacement for these columns to the top-of-wall height = 4 x 3.167 ft. height x 3.1416 (pi) x (1 ft.)$^2$ (radius) = **39.8 cu.ft. V-115 Support Columns Volume**.

V-210M has four footers that are 2.83 ft. square and about 2" high. This displacement would be 2.83 ft. x 2.83 ft. x 0.167 ft. x 4 footers = **5.34 cu. ft. for V-210 Support Footers**.

V-110M is supported by a 12' x 12' x 3.5 inch high pedestal. A 3.25 ft. triangular section is deleted from the southeast corner of the pedestal. The displacement volume for this pedestal is 12' x 12' x .29' = 41.8 cu.ft. Less the corner of .5 x 3.25' x 3.25' x .29' = 1.53 cu.ft. to get **40.3 cu.ft for V-110M Pedestal displacement**.

The pads on the V-6000C tank supports are only 1 inch high and less than a foot square. The displacement for these pads along with the support steel for the tanks is more than offset by the slope of the dike and the sump.

The 3 inch piping to these tanks is below the top of the dike. The 3 inch, Schedule 40 pipe is 3.5 inches (0.2917 ft.) diameter and would have a volume of .0668 cu.ft. per lineal foot. The total length of piping plus the length of the piping supports is approximately 154 ft. The containment volume lost to the piping is .0668 cu.ft./ft. x 154 ft. = **10.3 cu.ft. Containment Lost to Piping**.

The net containment volume for this dike is then the gross containment volume less the displacement for the tank footers or support pads and the piping within the containment or 2,907.3 - 39.8 - 5.34 - 40.3 - 10.3 = **2,811.6 cu. ft. Effective Containment**.

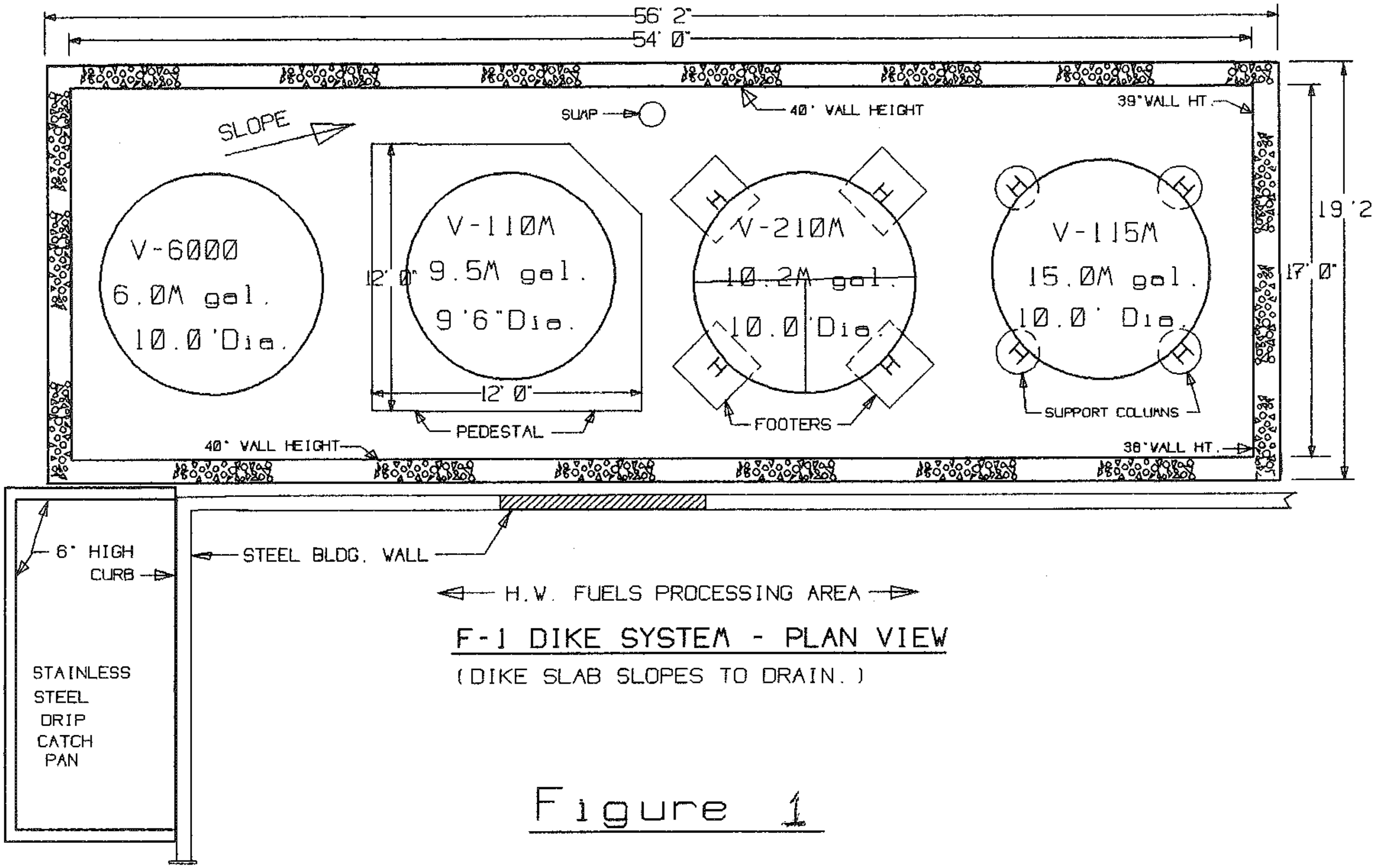
The rainfall area for the dike includes the top-of-wall area for 13.5 inch wide wall caps and is 56.167' x 19.167' = **1,076.6 sq.ft.**

The containment volume required for the 25-year, 24 hour rainfall of 4 inches would be the rainfall area multiplied by 4 inches (.333 ft.) or 1,076.6 sq.ft. x .333 ft. = **358.5 cu.ft. Rainfall**.

The volume of the largest tank in the dike is 15,000 gallons divided by 7.481 cu.ft. per gallon or **2,005.1 cu.ft.**

The total minimum containment volume required by OAC 3745-55-293(E)(1)(b) for this dike is the sum of the rainfall volume and the 15,000 gallon tank volume or 358.5 + 2,005.1 = **2,363.6 cu. ft. Required Containment Volume**.

The F-1 Dike containment exceeds the required minimum volume of 2,363.6 cu.ft. by 2,811.6 cu.ft. - 2,363.6 cu.ft. = **448.0 cu.ft. or 3,351.5 gallons** containment volume over required minimum volume.




F-1 DIKE SYSTEM - PLAN VIEW

(DIKE SLAB SLOPES TO DRAIN.)

Figure 1